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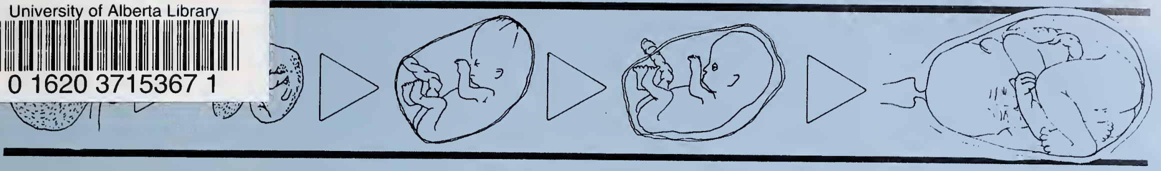
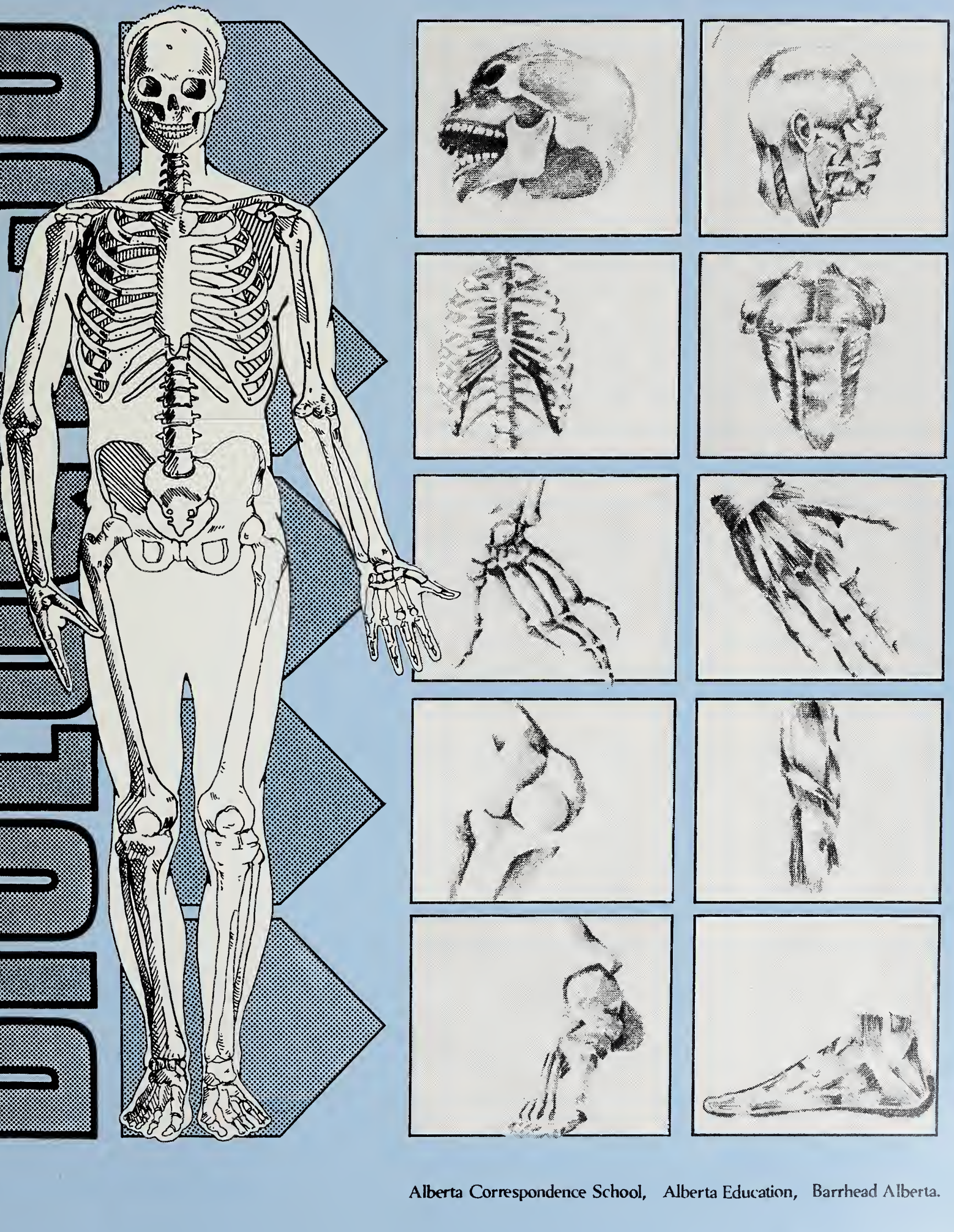


BIOLOGY 30



Alberta Correspondence School, Alberta Education, Barrhead Alberta.

FEB 2 2 199

Biology 30

LESSONS 1-20

Distance Learning

Alberta
EDUCATION

Biology 30
Student Module
Lessons 1-20
Alberta Correspondence School
ISBN No. 0-7741-0452-X

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UNIVERSITY LIBRARY

Time Element

Most of you taking this course have an objective in mind. Please arrange your schedule carefully in order to give yourself adequate time to study and become conversant with the contents of the course material. It is to your advantage to complete and submit all lessons for correction and grading early so that these lessons may be corrected and returned to you prior to writing the final examination. After you have written your final examination, please allow adequate time for grading, computation of final grades and the release of such information.

How To Begin

1. Carefully remove the staples from this workbook and put the course in a ring binder. To separate the pages, open the book at the center and gently but firmly spread the two halves away from each other. This will release the staples. Remove the pages a few at a time from the ends of the staples.

2. Assemble the basic supplies you require such as pens, pencils, ruled or plain loose-leaf sheets, a ruler, eraser or liquid paper.

3. Complete the Science Questionnaire and return it with the first lesson that you sent in.

4. The Laboratory Kit is an integral part of your course. You are strongly advised to either purchase a laboratory kit from the Alberta Correspondence School in order to complete the laboratory activities OR make arrangements to use a school laboratory.

Your Textbooks

The textbooks prescribed for the Biology 30 course are:

1. *Biology of Ourselves, A Study of Human Biology.*
   by Gordon S. Berry. 1982 Edition.

2. *Biology* by Edward J. Kormondy and Bernice Essenfeld

Your primary reference for the Biology 30 course you are about to study is: *Biology of Ourselves, A Study of Human Biology* by Gordon S. Berry. 1982 Edition.

Initially, it is to your advantage to familiarize yourself with the textbook. An hour or two spent doing so is time well spent.

Examine the table of contents and familiarize yourself with the major themes and topics covered in each chapter.

A look at the section entitled "To the Student" will provide you with some information about the author's rationale for the content and presentation.

You will find a glossary toward the back of the textbook. It is a very important but often ignored. The glossary contains definitions of key biological terms used throughout the textbook.

Welcome

Hello. Welcome to the Biology 30 course via correspondence. We enjoy teaching biology and hope you enjoy your studies while working with us.

Objectives

One objective of the course is to help you become conversant with the techniques, procedures and concepts included in the laboratory phase of a high school biology course. The major course content is designed to provide you with a sound knowledge of the principles, concepts and processes set out in the current high school biology curriculum. More specifically our objectives include guiding you in your examination of selected cell structures and their functions, and providing for you an introduction to a chemical basis for life. In putting together the course material we have attempted to facilitate your examination of the following human processes:

(a) Alimentation and nutritional needs
(b) Circulation of body fluids
(c) Breathing and gas exchange
(d) Cellular respiration
(e) Movement and support
(f) Regulation of body fluids
(g) Nervous and hormonal control systems
(h) Reproduction

Studying Via Correspondence

As a student you will find that taking a course by correspondence is considerably different from taking a course in a classroom with a teacher. The onus for reading, studying and answering questions will be your own personal responsibility. You will be responsible for setting your own work timetable, disciplining yourself to study each lesson thoroughly and seeing that lessons are sent in regularly.

Because your teacher is not immediately present, you will find you will be much more involved in active participation. This is an advantage to you for as the saying goes ''we learn by doing''. It is also our hope you will find this challenge both interesting and exciting, and we are confident you will succeed in your efforts if you give yourself a fair chance. We have confidence in you and your ability. Will you justify that confidence?

The index for your textbook, located at the back of the book, is very useful when researching a topic or theme.

Examine the chapters in your textbook. Each chapter contains a major subject or topic heading in large bold letters. Sub-headings outlining the major topics dealt with in the chapter are also included.

Each chapter contains photographs, drawings, illustrations and tables which supplement and clarify the contents.

At the end of each chapter are questions for review. Study these carefully. The section entitled, ''Some Facts to Know'' provides for you a chance to test your comprehension of the material studied. Spend some time scanning the ''Case Studies'' and ''Questions For Research'' included in each chapter. These make the subject more interesting.

Obtaining the Text

The textbook is supplied with the course to all non-classroom students. Students attending school and those non-classroom students studying the course outside the Province of Alberta are required to obtain their own textbook.

Classroom students may make arrangements for the loan of the text through their school. Alternatively the text can be purchased through the School Book Branch. Further information may be obtained from:

Learning Resources
Distributing Centre
10410 - 121 Street
Edmonton, Alberta
T5N 1L2

Phone: 427-2767

Course Content

There are twenty lessons in your Biology 30 course. Eighty percent of the course, Lessons 1-16, covers the core material to be studied.

The Biology 30 final test, prepared and administered by the Alberta Correspondence School, is based on all twenty lessons.

The Provincial Diploma Examination in Biology 30, prepared and administered by Alberta Education, Student Evaluation Branch, include materials dealt with in Lessons 1-16. Please study the material dealt with in these lessons thoroughly. Do not hesitate to review each lesson repeatedly.

Completing the Lessons

We feel you will gain maximum value and enjoyment from this course if you attempt to use the following guidelines.

1. Establish a regular timetable for studying.
2. Work in an area where you will not be disturbed.
3. Have all your materials close at hand.

indicates text reading assignment

4. Read the teaching notes and the textbook as suggested in each lesson. Study all diagrams and charts as they are mentioned in the body of information. Read the material more than once if you are having difficulties comprehending the concepts and then think very carefully about what you have read.
5. Once you have completed the reading assignment, begin the exercises. Read the questions carefully so that you understand exactly what has been asked or what you have been instructed to do. Think about your answers very carefully, then record them.
6. Please do all written work in **blue or black** ink and on the sheets provided. Use good English to answer the questions and write as clearly as you can. It will take anywhere from six to ten hours to complete a lesson.

indicates self-correcting exercise

7. In each lesson there are a number of **self-correcting exercises** to be completed by you. The answers to the questions in these exercises are provided at the end of each lesson. Check your answers and evaluate your performance. **Do not** send in exercises for which the answers are provided.
8. If you have questions regarding your course, please contact the Alberta Correspondence School. We are here to assist you and your questions will certainly help us serve you better. **You may phone us at 674-5333**.
9. Upon completion of each lesson please submit to the Alberta Correspondence School the section marked "**Exercises To Be Sent In For Correction**". The pages in your lessons containing only teaching notes should **not** be submitted.
10. When corrected lessons are returned to you, you should review them carefully and correct the errors using the comments and references to assist you. If you correct the errors, your understanding in those areas which have given you the most trouble should be greatly improved. This should also result in your receiving a better final mark in the course.
11. Try to submit your lessons regularly, for example, one or two lessons every week or a lesson every two weeks. Work out a completion schedule for yourself using the guide provided at the end of the Introduction.

Laboratory Activities

It is hoped that the laboratory activities will provide some challenge for you, lead to some critical thinking and give you some insight into the significance of inquiry as an aspect of present day biological studies.

The laboratory activities may be carried out at home or in a school laboratory. If carried out at home you will require a flat surface such as a table top or kitchen counter; a sink with running water and electricity or a safe heat source.

Besides providing you with some biological understandings, we hope these activities will assist you in becoming conversant with the methods of science, help you develop laboratory skills, stimulate your enthusiasm for studying the course material and perhaps even develop a zest for further experimentation and scientific studies.

SI (The Latest Version of the Metric System)

The Change to Metric: Through the centuries, many measurement systems have evolved from numerous origins, convenient customs and local adaptations. Most systems have lacked rational structure. The Imperial system - using the yard, quart, and pound - is one such conglomeration of poorly related units.

About 200 years ago, France decided to bring order out of chaos and the metric system was born. Although strongly opposed at first, this new system proved effective and gained popularity, so much so, that over 90% of the world's population now lives in countries that have adopted or are changing to the metric system.

Various Versions of Metric Systems: There have been several metric systems, but each new version has added more metric units, causing unnecessary congestion. To make matters worse, in some applications there has been a mixture of both Imperial and metric units. Thus, something had to be done to clean house.

The Latest Version of the Metric System: In 1960 the International System of Units was established as a result of a long series of international discussions. This modernized metric system, called SI, from the French name, Le **Systeme International** d'Unites, is now, as a general world trend, to replace all former systems of measurement, including former versions of the metric system. Canada has decided to convert to SI.

Many European nations are making the change to SI - a change from former metric practice. The United Kingdom, Australia, New Zealand, South Africa and others are adopting SI, while countries such as India, China and Japan are updating their metric practice to conform to SI. In the United States, major industries are tooling up for metric conversion and their choice, too, is SI.

It's SI, not S.I. - omit the periods.

It's just called SI not the ''SI system'', since the ''S'' stands for the word ''system''.

SI is Similar but Different: SI includes familiar metric units such as the metre and kilogram. There are, however, a number of changes from former metric systems. For instance, the centigrade temperature scale is called the Celsius (pronounced sell-see-us) scale when used for general purposes. This is a change in name only, so that 20°C, formerly read as ''twenty degrees centigrade'', is now read as ''twenty degrees Celsius''. There is no change in the scale, only in the name. Water still freezes at 0°C and boils at 100°C (degrees Celsius, that is). This kind of change is not difficult for those who are familiar with older metric systems.

Numbers moulded metrics: The metric system was based on the convenience of the decimal number system. Units are related by factors such as 10, 100 and 1000. This makes computation in the metric system much simpler than that with Imperial measures. A great deal of the arithmetic merely involves the shifting of the decimal, without tedious calculations.

This course is written using SI units exclusively. The table of units below is a reference guide so you can easily understand what these units mean.

PLEASE: Try to think **SI Metric** and use these metric measures whenever possible.

Prefix	Symbol	Meaning	Multiplier	
* mega	M	one million	1 000 000	$= 10^{6}$
* kilo	k	one thousand	1 000	$= 10^{3}$
hecto	h	one hundred	100	$= 10^{2}$
deca	da	ten	10	$= 10^{1}$
*		one	1	$= 10^{0}$
deci	d	one tenth of a	0.1	$= 10^{-1}$
* centi	c	one hundredth of a	0.01	$= 10^{-2}$
* milli	m	one thousandth of a	0.001	$= 10^{-3}$
micro	μ	one millionth of a	0.000 001	$= 10^{-6}$
nano	n	one billionth of a	0.000 000 001	$= 10^{-9}$
* - most commonly used				

Table 1: **Prefixes Used in the Metric System**

Table of SI Units and Non-SI Units Permitted For Use With SI

The table that follows is put in the order of most probable frequency of use. Units that would be used frequently are put first, and units less frequently toward the end.

QUANTITY	UNIT	SYMBOL	NOTES
length	nanometre micrometre millimetre centimetre metre kilometre	nm µm mm cm m km	Nanometre (nm) replaces the old metric unit millimicron (mµ) Micrometre µm replaces the old metric unit micron 1 nm = .000 001 mm 1 µm = .001 mm
area	square centimetre square metre	cm^2 m^2	
volume	cubic centimetre cubic metre millilitre litre	cm^3 m^3 mL L	1 cm by 1 cm by 1 cm There are 1000 mL in 1 L. 1 L is the volume of a cube 10 cm by 10 cm by 10 cm.
mass	milligram gram kilogram tonne	mg g kg t	1 t is 1000 kg.
temperature	degree Celsius	°C	A comfortable room has a temperature of 20°C. Body temperature is 37°C.
time	hour minute second	h min s	
pressure	pascal kilopascal	Pa kPa	The atmospheric pressure is about 100 kPa. One millimetre of mercury or one torr is about 133 Pa.
energy, work	joule	J	1 Cal = 4.2 kJ (approx); 1 cal = 4.2 J (approx) (1 Cal = 1000 cal).
force of gravity	newton	N	Newton - the force that, when applied to a body having a mass of one kilogram, gives the body an acceleration of one metre per second squared.
Numeric dating	In SI, dates are expressed in this **exact** order: YEAR-MONTH-DAY. The month is not written out and times can be added by: hour - minute - second. Example: 1977 10 31 08 30		

Table 2: Common Metric Units Used in Biology

Rules for Writing SI

1. Symbols are never pluralized: 45 g (not 45 gs)

2. Never use a period after a symbol, except when the symbol occurs at the end of a sentence. This is done because SI symbols are SYMBOLS they are NOT abbreviations.

   Example: the symbol for kilogram is ''kg'' NOT ''kg.''.

3. Symbols should usually be used and unit names not mixed with symbols.

   Example: 10 kg (preferred), ten kilograms (accepted), never 10 kilograms.

4. Always use a full space between the quantity and the symbol: 45 g (not 45g)

   Exception: For Celsius temperatures the degree sign occupies the space. 32°C (not 32° C or 32 °C)

5. Use decimals, not fractions: 0.25 g (not 1/4 g) (the decimal is a point on the line in English).

6. A zero is always used before a decimal marker: 0.45 g (not .45 g)

7. Symbols are written in lower case, except when the unit is derived from a proper name:

   m for metre; s for second; but N for newton; A for ampere; degree Celsius °C is the only one to be upper case in both name and symbol.

8. Prefixes are printed in Roman (upright) type without spacing between the prefix and the unit symbol: kg for kilogram, km for kilometre.

9. Only one prefix is applied at one time to a give unit: megagram or tonne, NOT kilokilogram

10. Use spaces to separate long lines of digits into easily readable blocks of three digits with respect to the decimal marker: 32 453.246 072 5

    Exception: A space is optional with a four-digit number: 1 234 or 1234.

Laboratory Guide

We trust that you will find the following notes useful in carrying out the laboratory activities.

Handling of Laboratory Equipment

1. You will not need to use a test tube holder for most of the investigations, but where you are handling hot test tubes you can make your own holder. A simple test tube holder can be made by folding a square piece of paper into strips and then wrapping it around the test tube as illustrated below.

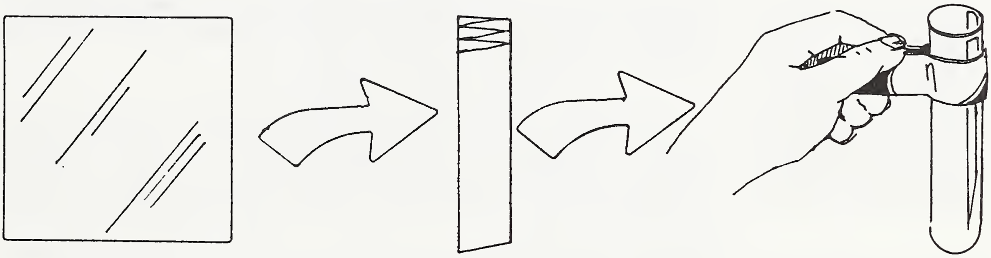


Figure 1: Test Tube Holder

Another way that you can make a test tube holder is to use a clothes pin.

2. A **test tube rack** is a convenient tool if you are handling a number of test tubes at once. The rack will keep your test tubes in an upright position and orderly sequence. A simple rack can be made from a shallow cardboard box as illustrated in Figure 2. On the top, make the holes slightly larger in diameter than the test tubes while the bottom holes can be about half the diameter. Make as many holes as are needed or that can be put into the space available. If you do not have a test tube rack, then a wide mouth jar can be used to place the test tubes in as illustrated in Figure 3.

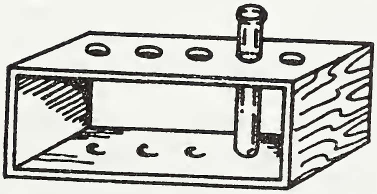


Figure 2: Test Tube Rack

Figure 3: Beaker with Test Tubes

Policy on Handling Chemicals

The following information is available to all students enrolled in courses offered by the Alberta Correspondence School which make use of chemicals:

1. A list of chemicals accompanies each laboratory kit that students purchase.

2. A warning notice is provided with each laboratory kit containing chemicals. This notice states that "**all chemicals must be regarded as poisonous**." On this notice students are informed to

   (a) **store all chemicals out of reach of children.**
   (b) **use the chemicals as instructed in the lesson notes.**
   (c) **dispose of these chemicals promptly after use.**

3. The lesson material that deals with handling chemicals contains information as to what students need to do if any of these chemicals are spilled on the work surface or on the skin and clothing.

   In general, if chemicals are spilled on the work surface soak them up with a sponge. Wear safety gloves while doing this procedure. Then dilute with excess water and rinse the chemicals down the drain. Wash the sponge carefully making sure the chemical residues have been washed away. The chemicals contained in each laboratory kit are not likely to damage the work surface (i.e. counter, table); however, it is recommended that students use a thick layer of paper towel or a rubber mat to protect the work surface from any spills that may occur.

   If chemicals come in contact with clothing, remove the clothing immediately and rinse thoroughly with excess water. Wear protective plastic gloves while doing this procedure.

   If the student's hands come into contact with chemicals they are to be washed thoroughly with water and then soap and water.

4. Information regarding the method of disposing of chemicals is included in the Introduction of Biology 30 as well as within the lessons. In general, liquids and solids are to be diluted with water and flushed down the drain with large quantities of water. These solids and liquids can also be flushed down the toilet where they are automatically diluted. A few of the chemicals found in the lab kit need to be disposed of in a special manner. In these particular cases extra chemicals will be provided in the laboratory kit to safely dispose of these chemicals.

5. It is recommended that students wear plastic gloves, some eye protection (goggles), and some protective clothing (i.e. lab coat or smock) when dealing with chemicals.

6. Washing procedure if acids and/or alkali (bases) get into the eyes:

   (a) **Acids:** wash eyes with cool water for 20 min. and seek immediate medical attention.

   (b) **Bases (Alkali):** wash eyes with cool water for 25 min. and seek medical attention immediately.

7. It is imperative that students do all their lab work near the sink or where water is available.

8. Students must remember to wash their hands thoroughly after each experiment.

Chemicals Used in Biology 30

Chemical	Where is the chemical used?	Description and Use	Is this chemical hazardous?	Method of Disposal
Benedict's Solution	Experiments in Lesson 2 and Lesson 4	- an alkaline solution of copper hydroxide and sodium citrate in sodium carbonate - used as a mild oxidizing agent or as a test for easily oxidizable groups such as aldehyde groups. Glucose reacts with Benedict's solution to form cuprous oxide. - tests for the presence of reducing sugars	No	- dilute with excess water and pour down the drain
Iodine Solution	Experiments in Lesson 2 and Lesson 4	- dark blue-black liquid - insoluble in water - soluble in alcohol and carbon tetrachloride (CCl_4) - tests for the presence of starch **Handling:** wear protective gloves. Avoid contact with skin and eyes. **Storage:** store out of direct sunlight and away from acetylene, ammonia, hydrogen.	Yes	- cautiously add iodine solution to a large volume of a sodium thiosulfate solution. Leave the solution to stand for awhile. Then add sodium carbonate or dilute hydrochloric acid (0.1 M) solution to neutralize the liquid. Then wash into drain with large excess of water.
Starch Suspension	Experiments in Lesson 2 and Lesson 4	- white liquid suspension - formed by adding 1 teaspoon of cornstarch to 50 ml of water - composed of polysaccharides	No	- dilute with excess water and pour down the drain
Glucose Solution	Experiments in Lesson 2 and Lesson 4	- transparent solution formed by dissolving 1 teaspoon of glucose in 10 ml of warm water - composed of a simple sugar (monosaccharide) - used in the test for reducing sugars. Glucose reacts with Benedict's solution to form cuprous oxide.	No	- dilute with excess water and pour down the drain
Unknown A	Experiment in Lesson 4	- an organic molecule	No	- dilute with excess water and pour down the drain
Glycogen Solution	Experiment in Lesson 4	- the transparent solution is a carbohydrate - used in the test for starch	No	- dilute with excess water and pour down the drain
Biuret Reagent	Experiment in Lesson 4	- prepared by adding 25 ml of a 3% solution of copper sulfate per litre of 10% potassium hydroxide - tests for the presence of protein	No	- dilute with excess water and pour down the drain
Gelatin Solution	Experiment in Lesson 4	- prepared by adding 5g of gelatin to 50 ml of water	No	- dilute with excess water and pour down the drain
Albumin Solution	Experiment in Lesson 4	- prepared by mixing egg whites and water	No	- dilute with excess water and pour down the drain
Sudan IV Reagent	Experiment in Lesson 4	- red solution - tests for the presence of fats - this reagent can stain skin and clothing	No	- dilute with excess water and pour down the drain

Solution Preparation

1. **Egg Albumin** solution may be made simply from fresh eggs. Carefully separate the white from the yolk and then add about 8 times the water to the white. Gently beat the albumin in the water so they mix thoroughly. Strain this through a cheese cloth or any such material. Use the filtrate (liquid that comes out) for your experiments.

   Also, egg albumin solution can be made from powdered egg albumin. Add about 1 g of powdered egg albumin (about ½ of the package in the lab kit) to 10 mL of water. Gently stir and don't allow the mixture to foam. Once the powder has dissolved add enough water to make up 100 mL of solution. The water may be measured in the small beakers or the small graduated plastic cups in your kit. This solution is used in Lesson 4.

2. **Gelatin** can be made by suspending about 1.5 g (½ teaspoon) of gelatin in 30 mL of water. Heat in a water bath (double boiler), till the gelatin dissolves and remove. Gelatin can be readily purchased at a grocery store. Gelatin is required in Lesson 4.

3. **Glucose** solution is made by dissolving glucose in water. The package in the laboratory kit contains glucose. Glucose solution is needed in Lessons 2 and 4. Refer to the instructions in each laboratory exercise when making up this solution.

4. **Glycogen** solution is available in the laboratory kit. If you are working in a laboratory, you may have to ask your supervising teacher for the solution. Glycogen is expensive and often is not carried in many laboratories. Glycogen solution is to be used in Lesson 4.

5. **Iodine** solution is used to identify the presence of starch. If the solution is dilute, a positive test will be bluish or purplish color. On the other hand if the iodine solution is strong, then the test will be very dark blue, purple or even black.

   Dilute iodine solution is available in the laboratory kit and it can be used directly. If you have concentrated iodine on hand, dilute by putting half a dozen drops in about a half test tube of water so it is orange to light brown in color. Iodine solution is required in Lessons 2 and 4.

6. **Millon's** reagent is used for identifying the presence of a protein. A positive test is a red precipitate that forms when the solution is heated. The Millon test may be carried out if the reagent is readily available. It is not enclosed in the laboratory kit. Note the results given.

7. **Starch solution** can be made by dissolving about 2 g (1 teaspoon) of starch or cornstarch in 50 mL of boiling water. Starch solution is required in Lessons 2 and 4.

8. **Sucrose solution** is prepared by dissolving about 5 g (1 teaspoon) of sucrose or table sugar in 50 mL of water. Sucrose solution is required in Lesson 4.

Evaluation Procedure

Those students who have completed all of their lessons in Biology 30, may write the final test. The evaluation for the course will be based upon a total of 100 points made up as follows:

1. The lessons carry a weight of 30 points. You are required to complete and submit all 20 lessons for correction and grading prior to writing the examination.

2. The final test carries a weight of 70 points. The time limit will be a maximum of two and a half hours. No notes or textbooks are allowed. Non-classroom students may contact the Alberta Correspondence School regarding arrangements for writing the final test. You may write the test at the Alberta Correspondence School, the Edmonton Study Centre or under the supervision of a teacher. Classroom students attending school should discuss arrangements for times and place of writing with their school principals. Your final grade is computed based entirely on your performance on the lessons.

In summary, your final school grade for the course will be computed based on the following distribution of points.

Lessons	- 30 points
Final Examination	- 70 points
Total	- 100 points

In addition to the above-mentioned grade, you will be required to write the Grade 12 Provincial Diploma Examination prepared and administered by Alberta Education, Student Evaluation Branch. The overall final grade for the course is calculated by taking the average of the school grade assigned by the Alberta Correspondence School and the grade achieved on the Grade 12 Provincial Diploma Examination. The grades from each source carries a 50 per cent weight.

CHEMISTRY OF LIFE

The following list is an outline of the topics covered in this introductory reading:

1. Elements
2. Atoms
3. Ions
4. Molecules
5. Compounds: Organic and Inorganic
6. Formation of Compounds
7. Types of Chemical Bonds: Covalent and Ionic
8. Major Classes of Biological Compounds
    (a) Carbohydrates
    (b) Lipids
    (c) Proteins
9. Types of Chemical Reactions
    (a) Synthesis
    (b) Decomposition
    (c) Reversible
    (d) Exchange Reaction
    (e) Dehydration Synthesis
    (f) Hydrolysis

CHEMISTRY OF LIFE

Introduction

The purpose of this reading is to introduce the student to the chemical organization of matter. Although living things are diverse in appearance, habitat, etc., their basic chemical organization is remarkably similar. This reading provides the student with background information in the chemistry of living and nonliving matter. This background information will be helpful in understanding and interpreting the content of the lessons in this course.

Elements

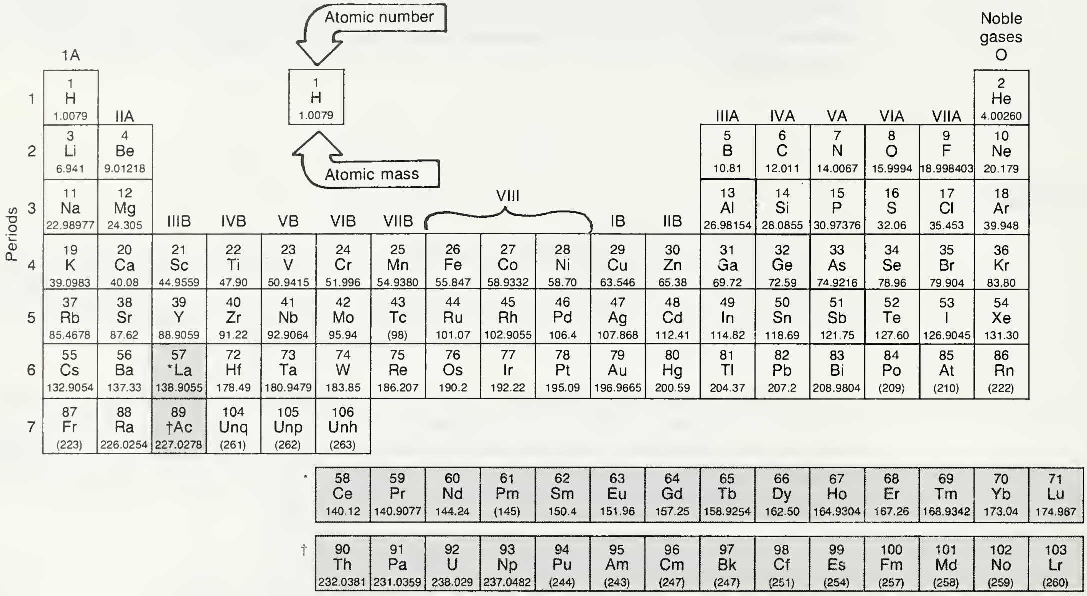
All living and nonliving things consist of matter. Anything that occupies space and possesses mass is considered to be matter. Matter can be found in a solid, liquid, or gaseous state. Air, water, and earth are all made up of matter. All matter is composed of basic building blocks called **elements**.

An element can be defined as a substance that cannot be separated into different kinds of matter. At present there are 106 elements which have been identified, with only 92 of these occurring naturally. Each element is designated by letter abbreviations called **chemical symbols**. The following table lists some of the more common elements, along with their chemical symbols.

Element	Symbol	Element	Symbol	Element	Symbol
Aluminum	Al	Fluorine	F	Nitrogen	N
Antimony	Sb	Gold	Au	Oxygen	O
Arsenic	As	Hydrogen	H	Phosphorus	P
Barium	Ba	Iodine	I	Potassium	K
Bismuth	Bi	Iron	Fe	Silicon	Si
Bromine	Br	Lead	Pb	Silver	Ag
Cadmium	Cd	Lithium	Li	Sodium	Na
Calcium	Ca	Magnesium	Mg	Sulphur	S
Carbon	C	Manganese	Mn	Tin	Sn
Chlorine	Cl	Mercury	Hg	Uranium	U
Chromium	Cr	Nickel	Ni	Zinc	Zn
Copper	Cu				

Figure 1: Common Elements and their Symbols

Chemists have been trying to classify elements by grouping together those with similar chemical and physical properties. One of the earliest attempts at classification was in 1869 when Dmitri Mendeleev published the periodic table of elements. Since Mendeleev's table was published about 30 more elements have been discovered but his basic format for classification is still used. The following is an example of a modern periodic table:


Atomic number
1
H
1.0079
Atomic mass

Periods	1A	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	Noble gases O
1	1 H 1.0079																	2 He 4.00260
2	3 Li 6.941	4 Be 9.01218											5 B 10.81	6 C 12.011	7 N 14.0067	8 O 15.9994	9 F 18.998403	10 Ne 20.179
3	11 Na 22.98977	12 Mg 24.305											13 Al 26.98154	14 Si 28.0855	15 P 30.97376	16 S 32.06	17 Cl 35.453	18 Ar 39.948
4	19 K 39.0983	20 Ca 40.08	21 Sc 44.9559	22 Ti 47.90	23 V 50.9415	24 Cr 51.996	25 Mn 54.9380	26 Fe 55.847	27 Co 58.9332	28 Ni 58.70	29 Cu 63.546	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.9216	34 Se 78.96	35 Br 79.904	36 Kr 83.80
5	37 Rb 85.4678	38 Sr 87.62	39 Y 88.9059	40 Zr 91.22	41 Nb 92.9064	42 Mo 95.94	43 Tc (98)	44 Ru 101.07	45 Rh 102.9055	46 Pd 106.4	47 Ag 107.868	48 Cd 112.41	49 In 114.82	50 Sn 118.69	51 Sb 121.75	52 Te 127.60	53 I 126.9045	54 Xe 131.30
6	55 Cs 132.9054	56 Ba 137.33	57 *La 138.9055	72 Hf 178.49	73 Ta 180.9479	74 W 183.85	75 Re 186.207	76 Os 190.2	77 Ir 192.22	78 Pt 195.09	79 Au 196.9665	80 Hg 200.59	81 Tl 204.37	82 Pb 207.2	83 Bi 208.9804	84 Po (209)	85 At (210)	86 Rn (222)
7	87 Fr (223)	88 Ra 226.0254	89 †Ac 227.0278	104 Unq (261)	105 Unp (262)	106 Unh (263)												

*	58 Ce 140.12	59 Pr 140.9077	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.96	64 Gd 157.25	65 Tb 158.9254	66 Dy 162.50	67 Ho 164.9304	68 Er 167.26	69 Tm 168.9342	70 Yb 173.04	71 Lu 174.967
†	90 Th 232.0381	91 Pa 231.0359	92 U 238.029	93 Np 237.0482	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)

Figure 2: Periodic Table of Elements

The same elements occur in living and nonliving things, but the amount of a particular element varies. For example, the oxygen found in the human body is the same as the oxygen found in water or in the air. It is hard to believe that everything on earth is composed of only these 92 naturally occurring elements and their combinations. The following table shows the major elements present in the human body and the percentages as related to those in the earth's crust.

Element	*Symbol*	*Approximate Percentage of Human Body*	*Approximate Percentage of Earth's Crust*
Oxygen	O	65.0	47.0
Carbon	C	18.5	0.03
Hydrogen	H	9.5	0.1
Nitrogen	N	3.3	Trace
Calcium	Ca	1.5	3.6
Phosphorus	P	1.0	3.6
Potassium	K	0.4	2.6
Sulphur	S	0.3	0.05
Chlorine	Cl	0.2	0.05
Sodium	Na	0.2	2.9
Magnesium	Mg	0.1	2.1
Iron	Fe	Trace	5.0
Iodine	I	Trace	Trace

Figure 3: Major Elements in the Human Body: Abundance by Weight in the Body and in the Earth's Crust

The human body contains about 24 elements in all; however, the elements carbon, hydrogen, oxygen, and nitrogen make up 96% of our body weight. These four elements are used in synthesizing the proteins, enzymes, and hormones that make up our bodies. The elements in our bodies are bonded together to form complex arrangements of a wide variety of chemical compounds (i.e. organic compounds). This particular concept will be discussed later in this introduction.

The following chart outlines the importance of some of the other minerals (elements) present in the human body:

Mineral	Symbol	Comments	Importance
Calcium	Ca	About 99% of calcium is stored in bones and teeth. The remainder of calcium is stored in muscle, soft tissue, and blood plasma. Recommended daily intake for children is 1.2-1.4 g and 800 mg for adults. Good sources of calcium are milk, egg yolks, and green vegetables.	Calcium is needed for the formation of bones and teeth, blood clotting, and muscle and nerve activity.
Phosphorus	P	About 80% of phosphorus is found in bones and teeth. The remainder is found in muscle, brain cells, and blood. The recommended daily intake for children is 1.2-1.4 g and for adults it is 1200 mg. Good sources of phosphorus are dairy products, meat, fish, poultry, and nuts.	Phosphorus is needed for the formation of bones and teeth and for the construction of enzymes. It also enables muscle contraction and nerve activity to take place.
Potassium	K	Potassium is found in intracellular fluid (i.e. the fluid inside cells). Nutritionists have not been able to ascertain what the daily recommended intake should be. Potassium is present in most foods.	Potassium is needed for the transmission of nerve impulses and muscle contraction.
Sulphur	S	Sulphur is found in proteins. Good sources of sulphur are beef, liver, fish, poultry, eggs, cheese, and beans.	Sulphur is needed for the production of hormones.
Chlorine	Cl	Chlorine is found in the extracellular and intracellular fluids (i.e. fluids outside and inside cells). The normal intake of NaCl (table salt) supplies the required amount of chlorine.	Chlorine is needed to maintain water balance in the cells. Chlorine is also needed for the formation of HCl (Hydrochloric acid) in the stomach. This acid helps to digest proteins.
Sodium	Na	Sodium is found in extracellular fluids and in the bones. Sodium is found in sodium chloride (table salt). The recommended daily dose of sodium chloride is 5 g.	Sodium is needed to maintain osmotic (water) balance in body cells. Sodium draws water with it; therefore, it is able to maintain osmotic pressure.
Magnesium	Mg	Magnesium is a component of soft tissues and bones. The recommended daily intake of magnesium is 250-350 mg. Magnesium is present in a variety of foods.	Magnesium is needed for the normal functioning of muscles and nerves.
Iron	Fe	About 66% of iron is found in the blood. The remainder of the iron is distributed in the skeletal muscles, liver, and spleen. Recommended daily intake for children is 7-12 mg and for adults 10-15 mg. Good sources of iron are meat, liver, egg yolk, dried fruit, nuts, and cereals.	Iron enables the blood to carry O_2 (oxygen) to body cells.
Iodine	I	Iodine is an essential component of thyroxin. Thyroxin is a hormone secreted by the thyroid gland. This hormone regulates metabolic activity. Good sources of iodine are iodized salt, seafoods, cod-liver oil, and iodine rich vegetables. The recommended daily requirement of iodine is 0.15-0.3 mg.	Iodine is needed to produce the hormone thyroxin. Thyroxin regulates metabolic activity.

Atoms: The Building Blocks of Matter

Each element is made up of units of matter called atoms. **Atoms** are the smallest particles of an element that can enter a chemical reaction. The atoms which make up a particular element are all of one type.

Atoms are made of even smaller particles. In the center of the atom is a dense area called the **nucleus**. The nucleus of the atom contains **neutrons**and **protons**.

Protons are positively charged particles. In all elements but hydrogen the nucleus also contains neutral particles called **neutrons**. Neutrons do not have an electrical charge. Surrounding the nucleus are small negatively charged particles called **electrons**. Electrons are located in different energy levels around the nucleus. They are in constant motion as they orbit around the nucleus. Most atoms possess the same number of protons as electrons. This makes the overall atom electrically neutral. The orbiting electrons stay close to the nucleus because of the strong attraction of the positively charged protons.

Although no one has actually seen an atom there are many theoretical views concerning its structure. The following diagram represents three views of the atomic structure of carbon:

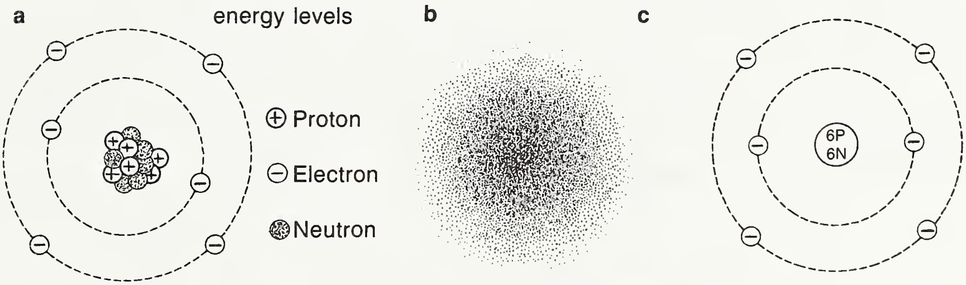


Figure 4: Three views of carbon's atomic structure: a. charge diagram; b. electron cloud; c. simplified structure.

The atoms of one element are different from the atoms of another element because they have different numbers of protons. For example, hydrogen, the simplest element, has only one proton. Nitrogen, on the other hand, has seven protons and oxygen has eight protons. It is the number of protons in the atom that gives an element its unique characteristics.

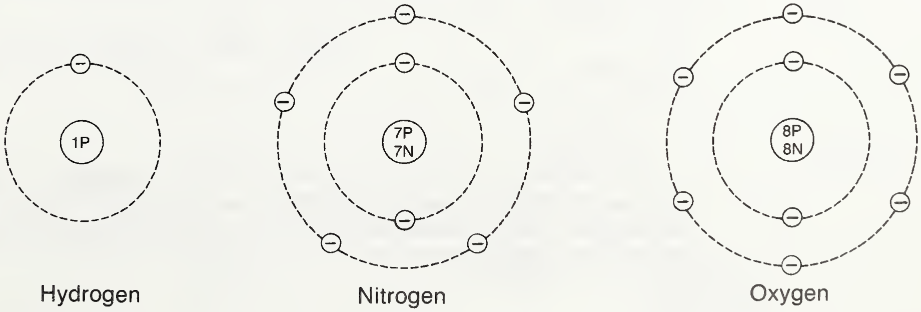


Figure 5: Atomic structure of three atoms common to all life: hydrogen, nitrogen, and oxygen.

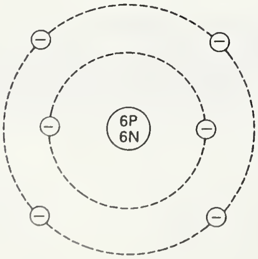
The periodic table is an organized way of classifying elements according to chemical and physical properties as well as atomic structures. Let us see the carbon atom as a specific example to introduce the terms **atomic mass** and **atomic number**. Refer back to Figure 2 (Periodic Table) and locate carbon in group IV. An atom of carbon is represented like this:

Carbon
6 **C**
12.011

One of the properties of atoms that we should note is the fact that they have mass. Almost all of this is accounted for by the mass of the protons and neutrons in the nucleus. In the case of the carbon atom, the atomic mass is 12 a.m.u. (atomic mass units). The gram atomic mass of an element is its atomic mass express in grams. This is often called the gram atom. Thus one can also say that a gram atom of carbon weighs 12 g (i.e. 12 grams). The atomic number refers to the number of protons or electrons in a neutral atom. In the case of the carbon atom the atomic number is 6 which means that there are 6 protons and 6 electrons in the carbon atom.

To summarize:

carbon atom



Atomic number: 6 (represents the number of protons (p) or electrons (e-) in a neutral atom)

Atomic mass: 12 (represents the sum of 6 protons and 6 neutrons in the nucleus of the atom)

The number of electrons in an atom is usually the same as the number of protons, but not always. When the numbers of electrons and protons are the same, the numbers of positive and negative charges within the atom are equal. These opposite charges cancel each other, making the atom neutral.

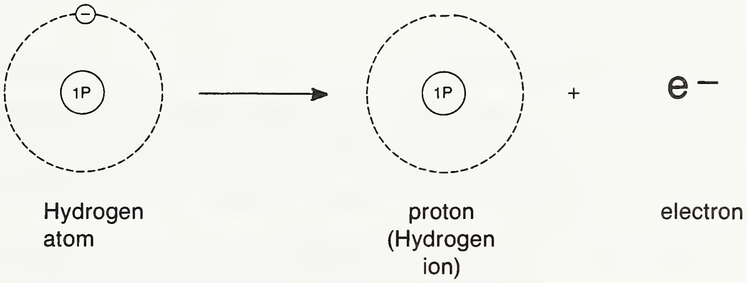
Ions

Under certain conditions, an atom may lose or gain electrons. This results in a different number of electrons than protons. In this case, the atom is not neutral; it has a charge. Atoms that have a charge are called **ions**. If there are more electrons than protons, an ion is negatively charged. On the other hand, if there are fewer electrons than protons, an ion is positively charged. It is important to note that an atom may lose electrons or gain electrons in forming an ion, but the number of protons does not change.

Ions frequently participate in the chemical reactions within cells. One of the most common ions in living things is the hydrogen ion (H^+). It is a hydrogen atom without its single electron. Therefore the hydrogen ion is simply a proton. Other important ions are the sodium ion (Na^+) and the chloride ion (Cl^-).

The following is a diagrammatic representation of how ions are formed. Symbols: **P** represents protons, **N** represents neutrons, and **e**$^-$ or – represents electrons.

1.

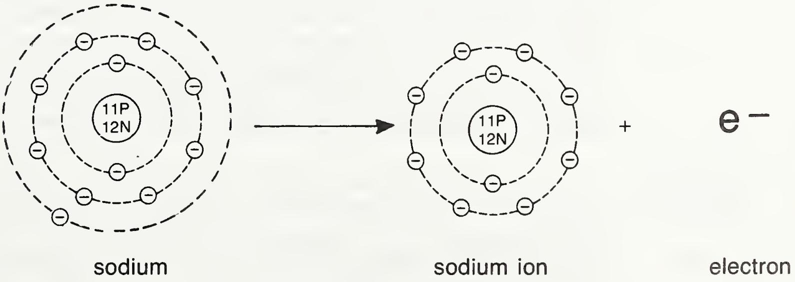


Equation:

$$H \longrightarrow H^+ + e^-$$

hydrogen atom		hydrogen ion		electron (lost from the hydrogen atom)

2.

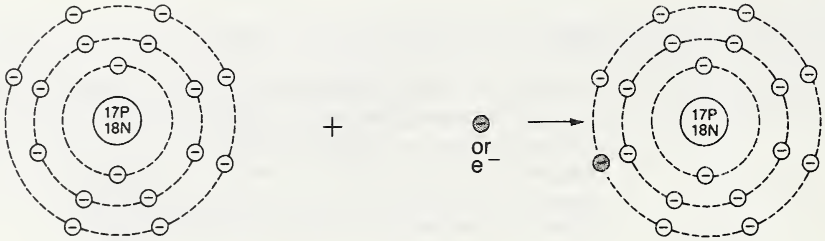


Equation:

$$Na \longrightarrow Na^+ + e^-$$

sodium atom		sodium ion		electron (lost from the sodium atom)

3.



Chlorine atom

Gains an electron

Chloride ion

Equation:

Cl	+	e^-	$\longrightarrow$	Cl^-
chlorine atom		electron (gained by chlorine atom)		chloride ion

Molecules

When two or more atoms combine the result is called a **molecule**. The atoms which combine to form a molecule may be the same kind or of different kinds. For example, two atoms of hydrogen often combine to form H_2, a molecule of hydrogen. The subscript 2 means that there are 2 atoms of hydrogen present in that molecule.

A molecule containing different kinds of atoms is called a **compound**. You can have complex arrangements of atoms as in glucose ($C_6H_{12}O_6$).

Chemical Compounds

A **compound** is a chemical substance that is made up of two or more elements and which has properties different from those of its elements. Sodium chloride (NaCl - common table salt) is a compound because it can be separated into sodium (Na) and chlorine (Cl), which are elements. Sodium chloride (table salt) does not resemble sodium or chlorine at all: table salt is made up of white grains, whereas sodium is a white metal and chlorine is a greenish-yellow gas. If you heat up sodium metal in a glass container and then pass chlorine gas into the container through a tube, sodium chloride (table salt) will be formed. **Please do not attempt to duplicate this procedure. It is considered to be dangerous.**

Every compound has a specific chemical formula. Chemical formulas are written using the symbols of the atoms found in the periodic table. The chemical formulas show the proportions of different atoms in various compounds. The formula for table salt (sodium chloride) is NaCl. The formula NaCl implies that there is one sodium atom for every chlorine atom in the sodium chloride molecule.

Water is a compound which is composed of hydrogen and oxygen atoms. Hydrogen and oxygen are gases at room temperature whereas water is a liquid. There are twice as many hydrogen atoms as oxygen atoms in water; therefore, the formula for water is H_2O.

Organic and Inorganic Compounds

Almost all compounds that contain carbon and hydrogen belong to a group of chemicals called **organic compounds**. Organic compounds often contain oxygen or nitrogen in addition to carbon and hydrogen. We will discuss organic compounds in greater detail a little later in this introduction.

Compounds that do not contain both carbon and hydrogen are called inorganic compounds. Many inorganic compounds contain minerals. Examples of inorganic compounds are carbon dioxide (CO_2) and water (H_2O).

Formation of Compounds

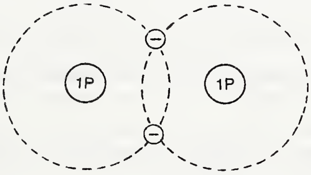
Compounds are formed when atoms combine or react with other atoms. When atoms combine they are held together by chemical bonds. Chemical bonds are formed by the interaction between the outer electrons of different atoms. There are two basic types of bonds that form between atoms: **covalent bonds** and **ionic bonds.**

Covalent Bonds

A **covalent bond** is formed when an atom shares its outer electrons with another atom, or in many cases, several atoms. Electrons can be shared between like atoms (i.e. H_2 - hydrogen gas) or unlike atoms (i.e. H_2O - water).

Examples of covalent bonds:

H_2:



Structural Formula

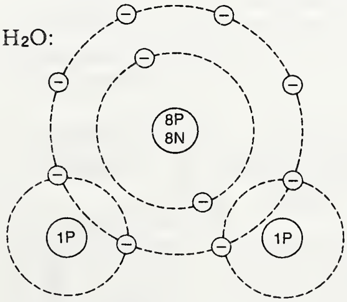
H—H
covalent bond

Molecular Formula

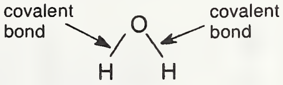
H_2

Two hydrogen atoms share electrons by covalent bonding to form a molecule of hydrogen.

H_2O:



Structural Formula



Molecular Formula

H_2O

One oxygen atom and two hydrogen atoms share electrons by covalent bonding. As a result a molecule of water is formed.

Covalent bonding does not necessarily involve the sharing of just one pair of electrons. Atoms can share one, two, or even three pairs of electrons. Short lines are used to indicate covalent bonds between atoms:

single covalent bond –
double covalent bond =
triple covalent bond ≡

Almost all of the organic compounds are made up of covalent bonds. An example of an organic molecule with a double bond is ethylene (C_2H_4). See Figure 6 for the covalent bonding in ethylene.

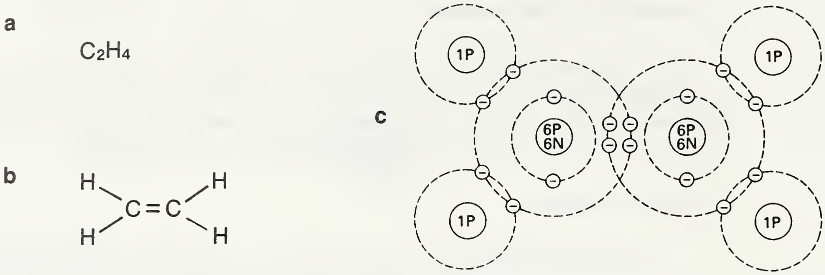


Figure 6: Covalent bonding in ethylene: **a.** molecular formula; **b.** structural formula; **c.** diagram, showing electron sharing.

Ionic Bonds

In ionic bonds electrons are not shared. Instead, electrons are transferred from one atom to another. In other words, one atom actually takes electrons from another atom. As a general rule metals ar eager electron donors and non metals are eager electron acceptors. For example, in the compound sodium chloride, chlorine atoms (non-metal) take one electron each from sodium atoms (metal). The sodium atoms become positive ions (Na^+) and the chlorine atoms become negative ions (Cl^-). These two ions (Na^+, Cl^-) are held together by the force of attraction between oppositely charged particles and together they form the compound sodium chloride (table salt).

The following diagram illustrates the ionic bond formed by sodium and chlorine to form the compound sodium chloride (table salt).

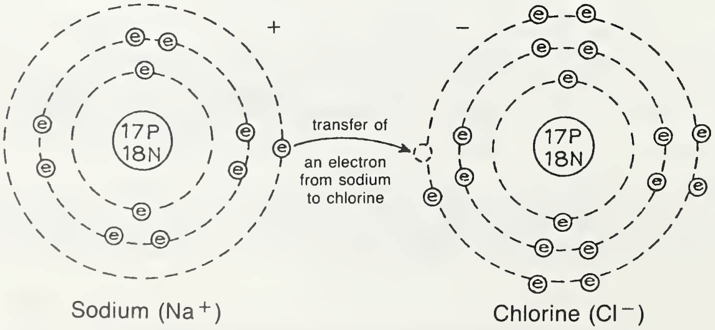


Figure 7: Transfer of Electrons in the Formation of NaCl (sodium chloride)

Many ionic bonds break easily in water, leaving the ions separated in the water. Compounds with covalent bonding do not break apart in water. Here the molecules stay intact. Therefore, most ionic compounds are not stable when they are dissolved in water, whereas most molecular compounds exhibiting covalent bonding are.

Example:

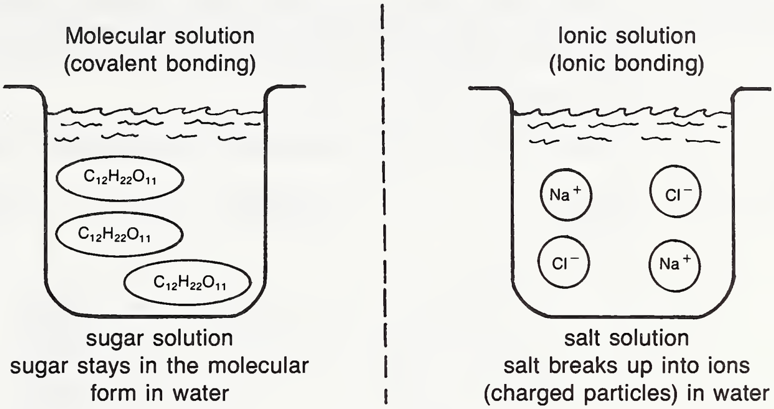


Figure 8: Compounds with covalent bonding do not break apart in water. These compounds remain in the molecular form and are considered to be very stable. Ionic compounds, on the other hand, break up into ions (charged particles) when they are dissolved in water. Ionic compounds are not stable in solution. The presence of ionic compounds in solution can be detected by sending an electrical current through the solution. The ions in the ionic solution are good conductors of electricity.

The Major Classes of Biological Compounds

The wide variety of organic compounds found in cells can be classified into three main groups: carbohydrates, lipids, proteins.

Carbohydrates:

We eat many foods that contain carbohydrates including potatoes, rice, bread, and cake.

Complex carbohydrates like starch are broken down during the process of digestion into simple sugars or **monosaccharides**. Simple sugars are the basic structural units of all carbohydrates. Glucose, fructose (fruit sugar), and galactose are the most common simple sugars with covalent bonds. Two monosaccharides linked together by covalent bonds form a **disaccharide** (double sugar).

Generalized Equation:
monosaccharide + monosaccharide → disaccharide

Specific Examples:
glucose + glucose → maltose (disaccharide)
glucose + fructose → sucrose (disaccharide)
glucose + galactose → lactose (disaccharide)

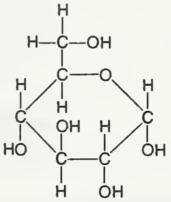
Many simple sugars bonded together in long chains form **polysaccharides**. Common polysaccharides such as starch and cellulose are made up of glucose units. Humans can digest starch but do not possess the necessary enzymes to digest cellulose. However, microorganisms living in the intestines of certain animals such as cows and termites are capable of breaking down the chemical bonds in cellulose. This enables these animals to use celloluse for food.

Plants store carbohydrates in the form of starch. Humans and animals store carbohydrates in the form of **glycogen**. Glycogen is stored in the liver and in muscle cells. Like starch, glycogen is composed of glucose units bonded together; however, glycogen has many more units of glucose attached together.

Structural Formulas of Three Common Simple Sugars (Monosaccharides)

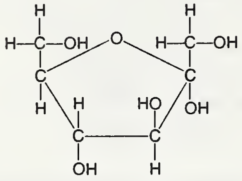
Glucose

($C_6H_{12}O_6$)



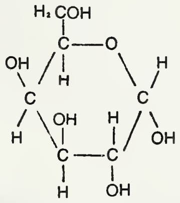
Fructose

($C_6H_{12}O_6$)



Galactose

($C_6H_{12}O_6$)



Structural Formula of a Disaccharide

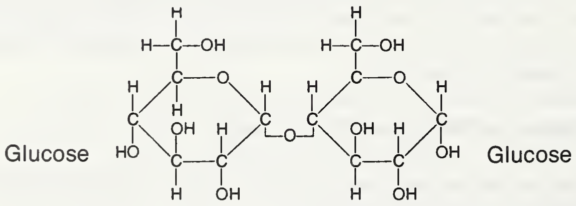


Figure 9: Maltose, a disaccharide, consists of two glucose molecules bonded together.

Simplified Structures of Polysaccharides

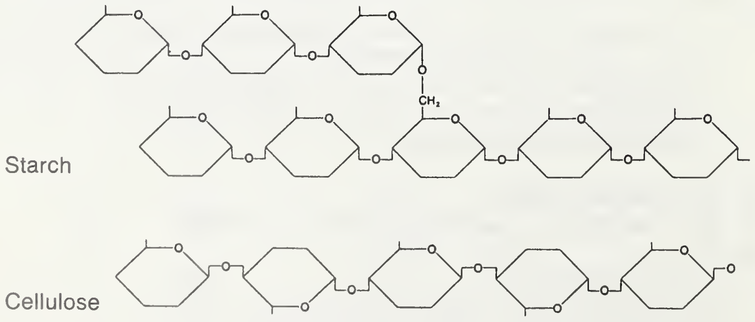


Figure 10: Structural formulas (simplified) of starch and cellulose. Both are made up of glucose subunits. Starch is highly branched; cellulose is generally a long, straight chain. Notice the difference between the bonding of glucose units in the two polysaccharides.

Lipids:

When you eat a piece of toast you consume mostly carbohydrates; however, when you butter the bread, you add lipids (fats) to your diet. Like carbohydrates, lipids contain carbon, hydrogen, and oxygen. Fats, oils, and waxes are lipids.

Mammals use fats to build parts of the cell membrane; they also store extra food in the food of fat. Oils are produced by both plants and animals. Corn oil and soybean oil are prime examples of oils obtained from plants. Our skin also produces oils.

Waxes are produced by both plants and animals. For example, the leaves and stems of plants are coated with wax which prevents them from drying out.

Fats and oils consist of three **fatty acid** molecules bonded to one molecule of **glycerol**. Waxes do not contain glycerol.

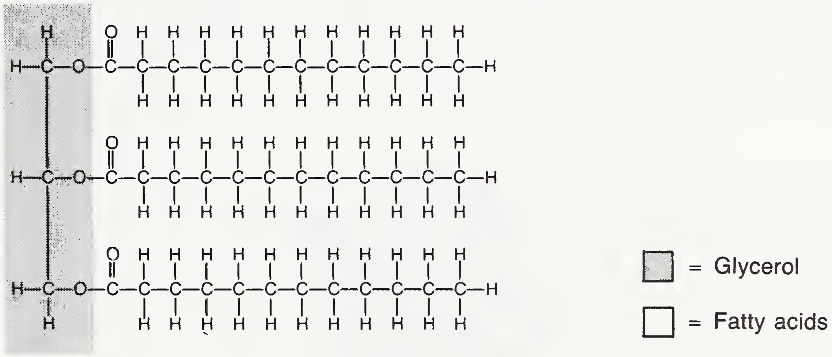
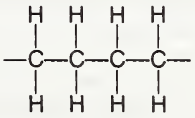


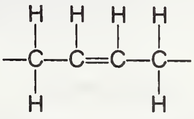
Figure 11: Structural formula of a fat molecule, showing glycerol bonded to three fatty acid chains.

Fats that have fatty acids with only single bonds between carbon atoms are called **saturated fats.**



$$\mathrm{-CH_2-CH_2-CH_2-CH_2-}$$

Fats that have fatty acids with double bonds between carbon atoms are called **unsaturated fats**.



$$\mathrm{-CH_2-CH=CH-CH_2-}$$

A **polyunsaturated** fat, on the other hand, has fatty acids with more than one double bond. Animals produce saturated fats whereas plants produce unsaturated fats.

Medical research has attributed the eating of large amounts of saturated fat to arteriosclerosis. This disease is caused by fatty deposits in the walls of blood vessels. The fat deposits greatly interfere with blood circulation. For this reason vegetable oils are considered better foods than animal fats.

Proteins

When you eat foods such as meat, fish, eggs, or dairy products you are consuming proteins. Proteins are large molecules that contain nitrogen, carbon, hydrogen, and oxygen. Protein foods are needed for the growth and maintenance of cells.

Proteins are made of small units called **amino acids**. There are 20 different amino acids that are found in proteins. Each kind of protein has its own specific arrangement of amino acids. Amino acids are linked together by peptide bonds and usually form long chains that contain between 40 to 500 amino acids. Insulin is a hormone that is secreted by the pancreas to control blood sugar levels. Insulin is a protein in nature and contains about 51 amino acids which are arranged in two chains. Protein chains are not long and straight; instead, most are coiled. Different proteins have distinct shapes because of the arrangements of amino acids.

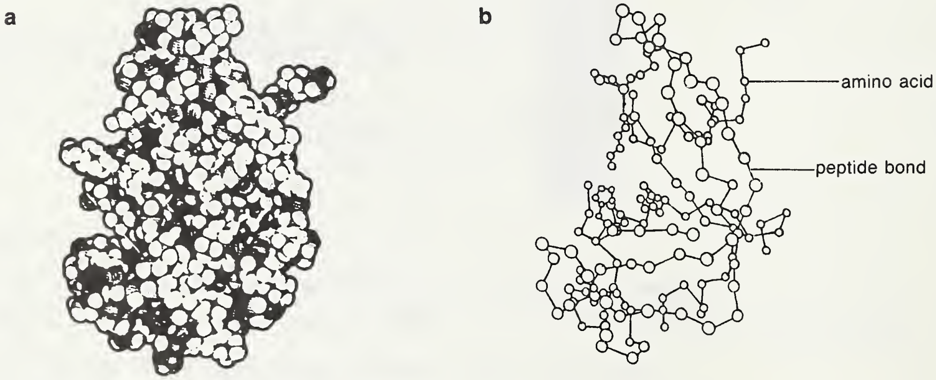
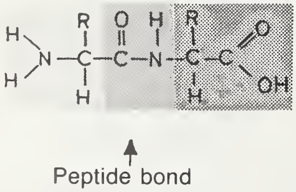


Figure 12: Twisting and folding of proteins: **a.** a space-filling model; **b.** three-dimensional model, showing linkages between amino acids in the chain.

Two amino acids bonded together are referred to as a **dipeptide**, and the bonds between amino acids are called **peptide bonds**. A **polypeptide chain** is a series of amino acids bonded together to form a large protein.



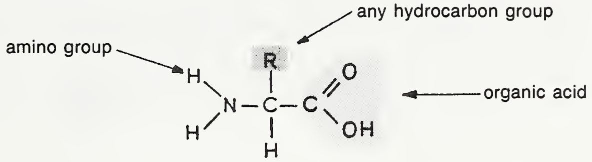
$$H_2N-CHR-CO-NH-CHR-COOH$$

R: represents any hydrocarbon group

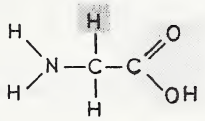
Figure 13: Dipeptide: two generalized amino acids connected by a peptide bond.

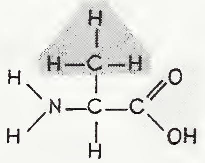
All amino acids have an amino group, an organic acid group, and an R group bonded to a carbon atom. The R group represents any hydrocarbon group. The R group will vary from one amino acid to another.

General structure of an amino acid



Examples of Amino Acids


Glycine


Alanine

Biological compounds such as carbohydrates, proteins, and fats are broken down by the process of digestion into monosaccharides, amino acids, fatty acids, and glycerol. After being absorbed into the bloodstream, these by-products of digestion enter the cells of the body. Several types of chemical reactions occur in cells. Some of these reactions build large molecules from smaller ones (i.e. anabolism). Other reactions break down large molecules into smaller ones (i.e. catabolism). Catabolic reactions occur mainly for the purpose of obtaining energy. There are many other types of reactions that take place in cells besides anabolism and catabolism but all chemical reactions involve the making and breaking of bonds between atoms.

Let us discuss six basic types of chemical reactions:

1. **Synthesis Reactions - Anabolism**

This type of reaction involves the building of large molecules from smaller parts. Two or more atoms, ions, or molecules combine to form new larger molecules. During a synthesis reaction new bonds are being formed within atoms.

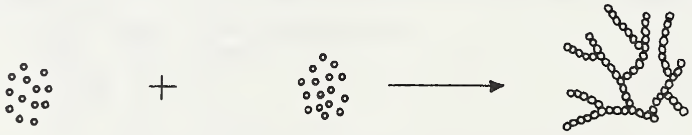
Generalized Synthesis (Anabolic) Reaction

A + B → AB

Reactants Endproduct

Examples of synthesis reactions which occur in our body includes the combining of glucose molecules to form glycogen and the combining of amino acids to form proteins.

SPECIFIC EXAMPLE



2. Decomposition Reactions - Catabolism

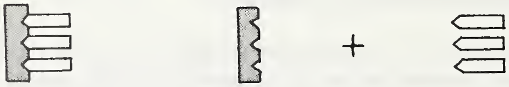
These types of reactions involve the breaking down of large molecules into smaller molecules.

Generalized Decomposition (Catabolic) reaction

$$\underset{\text{reactant}}{AB} \rightarrow \underset{\text{products}}{A + B}$$

Decomposition reactions are most important in digestion. Not only are large molecules (i.e. starches, proteins, fats) broken down into smaller molecules (i.e. glucose, amino acids, fatty acids, and glycerol), but smaller molecules are further decomposed in cells so that energy can be obtained from the bond breaking reactions.

Specific example:



3. Reversible Reactions

In this type of reaction the end product can revert back to the original combining molecules.

Generalized Reversible Reaction

$A + B \rightleftharpoons AB$

The energy that is derived from the breakdown of food molecules is stored in special molecules called ATP (adenosine triphosphate). When the energy is needed, the ATP breaks down into ADP (adenosine diphosphate) and PO_4 (phosphate group), and energy is released in the reaction. The phosphate group is symbolized as P. The cells of the body reconstruct ATP by using the energy derived from the catabolism of foods to attach ADP to PO_4 (phosphate group).

Specific example:

$$\boxed{ADP + P + Energy \rightleftharpoons ATP}$$

4. Exchange Reactions

Exchange reactions are partly synthesis and partly decomposition. The following equation is a generalized version of an exchange reaction:

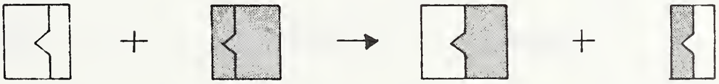
$AB + CD \rightarrow AD + BC$

The bonds between A and B and between C and D are broken in a decomposition process. New bonds are then formed between A and D and between B and C or between A and C and between B and D in a synthesis process.

A buffer system is an example of an exchange reaction. The main function of a buffer system is to maintain a steady state in the cells and surrounding fluids. A buffer system maintains homeostasis (a steady state) by eliminating strong acids or strong bases and replacing them with weak acids or weak bases that can change the normal acidity only slightly.

The following is a buffer reaction in which the body eliminates a strong acid to help maintain homeostasis:

$$HCl + NaHCO_3 \rightarrow NaCl + H_2CO_3$$



Hydrochloric acid (strong acid)
Sodium bicarbonate (weak base of buffer system)
Sodium chloride (salt)
Carbonic acid (weak acid)

In this reaction sodium bicarbonate acts as a buffer. Sodium bicarbonate ($NaHCO_3$) reacts with HCl (strong acid) to form H_2CO_3 (weak acid) and NaCl, a salt that has no effect on the acidity of cells or the surrounding fluids.

5. Dehydration Synthesis

Very often in chemical reactions, the atoms of different substances are joined together by covalent bonds. As a result, large molecules are formed from smaller ones. This process is referred to as synthesis. One type of synthesis reaction is **dehydration synthesis**. During dehydration synthesis, a water molecule is removed from the molecules participating in the reaction at the site where a new bond is formed. Dehydration synthesis results in the formation of disaccharides and polysaccharides from monosaccharides or simple sugar units, proteins from amino acids, and fat (lipid) from three fatty acids and glycerol. There is a specific enzyme that catalyzes each type of dehydration synthesis reaction.

Example:

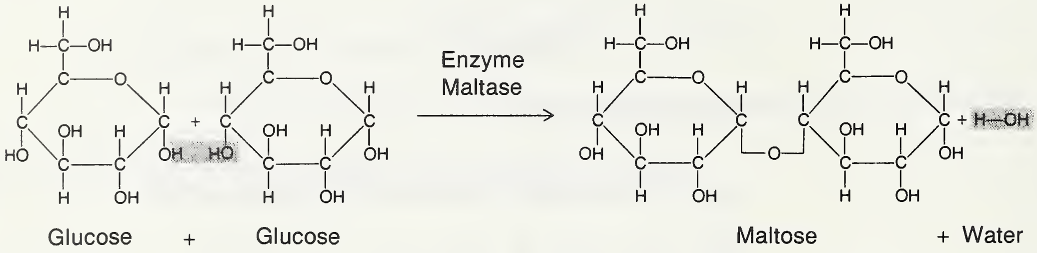


Figure 14: Dehydration synthesis of maltose. The enzyme maltase catalyzes the reaction of two glucose molecules to form maltose and water.

6. Hydrolysis

Hydrolysis is the opposite of dehydration synthesis. Here, molecules are taken apart by the addition of water.

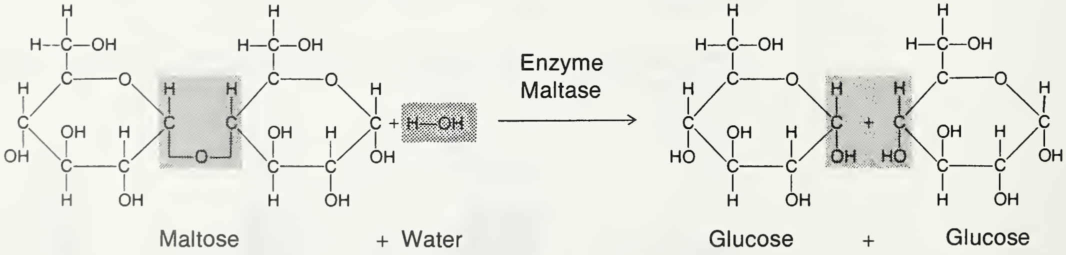


Figure 15: Hydrolysis of maltose. Maltose is broken down into two glucose molecules by the addition of water. Hydrolysis is the opposite of dehydration synthesis.

Hydrolysis reactions take place in the digestive tract as large food molecules are broken down into smaller ones and made ready for absorption by the cells of the body.

END OF INTRODUCTION

A Personal Guide for Lesson Completion in Your Correspondence Course

Below you will find a procedure for calculating the frequency with which you must submit lessons in your correspondence course to finish by the date you have chosen. Use it as a guide in working on your lessons and try to follow it as closely as possible. If you do, your lessons will not stack up at the end, either for you or for the teachers at the Alberta Correspondence School.

Study the example given below and complete pages 13 and 14 accordingly.

Example: Suppose it is September 3, and you have 20 lessons to do, and you wish to finish by December 1.

	Sept	Oct	Nov	Dec		
No. of days remaining =	(30 - 3)	+ 31	+ 30	+ 1	=	89 days

$$\frac{\text{No. of days}}{\text{No. of lessons remaining}} = \frac{89 \text{ days}}{20 \text{ lessons}} = 4.5 \text{ days/lesson}$$

You have approximately 4 days to do each lesson.

Lesson	To Be Completed By
Today's date	September 3
1	September 7 (add 4 to 20)
2	September 11 (add 6 to 26)
3	September 15
etc.	etc.
20	November 18

Note that since you rounded off 4.5 days to 4 days you will be finishing early. But this is much better than finishing too late by using 5 days/lesson.

Pages 34 and 35 MUST be submitted with Lesson 1 so that your teacher will know how you plan to schedule your lessons. These pages will be returned to you so that you can keep them handy as a guide.

1. NOTE: In order to write a final examination in the first semester, you are advised to have all lessons at the Alberta Correspondence School by December 1st of the same school year.

   In order to write the examination in the second semester, you are advised to have all lessons at the Alberta Correspondence School by May 1st of the same school year.

   By what date do you wish to finish the course? ______________________

2. Today's date is ______________________
   Now count the number of days on the calendar between now and the day you want to finish.

   Calculations:
   July =
   August =
   September =
   October =
   November =
   December =
   January =
   February =
   March =
   April =
   May =
   June =

   How many days are there? ______________________.

3. Now divide the number of days between now and the finishing date by the number of lessons you have left to do.

$$\frac{\text{No. of days}}{\text{No. of lessons remaining}} = \frac{\quad\text{days}}{\quad\text{lessons}} = \qquad \text{days/lesson}$$

   The last figure you have calculated is the number of days you have on the average to complete each lesson. (For example, if the number is 5.7 days/lesson you have approximately 5 days to work on each lesson).

4. Complete the chart on the next page.

Lesson	To Be Completed By
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

ADVANCE NOTICE CONCERNING BIOLOGY 30 PROVINCIAL DIPLOMA EXAMINATION

1. Students must write Provincial diploma examinations in Biology 30 in order to be recommended for high school credits.

   The Provincial diploma examination will be in addition to the final test in Biology 30 set by the Alberta Correspondence School.

2. The Provincial diploma examination will be administered by Alberta Education and will be held three times yearly — in the last weeks of January and June, and in early August.

3. The results of this examination will count 50 per cent toward the final mark for the subject, with the mark from the Alberta Correspondence School test and course work making up the remaining 50%.

4. The pass mark on both the Provincial diploma examination and the Correspondence School final test is 50 per cent.

   Students who fail their Provincial diploma examination can either request that their examination be remarked, or they can rewrite the examination at a later date.

   Students who fail the final test set by the Correspondence School can write an appeal test set by the Correspondence School. Such appeal tests must be written within 60 days and before the student's registration expires.

Classroom Students

Classroom students are those who are enrolled in at least one subject in a high school which follows the Alberta curriculum.

Classroom students will be expected to sit for both the Provincial diploma examination and their Correspondence School final test at the high school in which they are enrolled.

The Alberta Correspondence School final test will be mass-mailed to principals for all eligible students toward the end of January and late in May and August and the principals will set the test schedules. The Correspondence School will, however, provide tests for special sittings wherever feasible when special sittings are requested by principals.

Non-classroom Students

Non-classroom students are those who are not enrolled in a normal high school in Alberta or the Northwest Territories.

Such students are eligible to write the Correspondence School final tests at any time after the submission of at least eighteen satisfactory lessons in their course. This test may be written at any office of the Correspondence School, or under the supervision of an acceptable test supervisor.

It is recommended that this final test be written before the student sits for the Provincial diploma examination.

Non-classroom students are expected to write their Provincial diploma examination at the nearest convenient high school during one of the three yearly sittings. Information concerning the procedures for applying to write the Provincial diploma examination will be provided to non-classroom students at an appropriate time in their course.

Procedures for out-of-province students will also be provided at an approprite time.

Alberta Correspondence School Students

Students who are enrolled in Grade 12 diploma examination courses at the Alberta Correspondence School must apply to the Alberta Correspondence School to write the diploma examinations. At the time of application, these students must also indicate their choice of writing centre. For January and June examinations students may write at any High School. For August examinations students will be notified by the Alberta Correspondence School.

Provisions for Mature Students

For the purpose of the Diploma Examinations Program, a ''mature student'' is one who meets one of the following requirements as of **September 1**:

a. a student with a valid Alberta high school diploma
b. a student 20 years old or older
c. a student 19 years old, provided that after having reached the age of 18 years, the student left school and remained out of school for at least eight consecutive months.

Mature students may write any diploma examination for 100% of the final mark without having taken formal instruction in the course.

If a mature student enrolls in a diploma examination course at an approved Alberta high school, the final course mark will be either a blended one or if the school-awarded course mark is equal to or less than the diploma examination mark, the final mark will be the examination mark only.

How Your Lessons Will Be Graded

Your standings on the lessons will be indicated by means of letter gradings on the following basis:

Letter Gradings	Range of Scale
A	80 - 100%
B	65 - 79%
C	50 - 64%
D	40 - 49%
F	0 - 39%

We wish you success and enjoyment in this course.

TABLE OF CONTENTS

Lesson 1: The Cell and Its Parts

Lesson 2: Physical Processes in Cells

Lesson 3: The Human Digestive System

Lesson 4: Nutrition

Lesson 5: Digestion

Lesson 6: Cellular Respiration

Lesson 7: Human Skeleton and Muscles

Lesson 8: The Respiratory System

Lesson 9: The Heart and Circulation of the Blood

Lesson 10: Blood Structure and Function

Lesson 11: Central Nervous System

Lesson 12: Sensory Receptors

Lesson 13: The Endocrine System

Lesson 14: The Excretory System

Lesson 15: The Reproductive System

Lesson 16: Pregnancy and Childbirth

Lesson 17: Plant Anatomy and Physiology

Lesson 18: Leaf Structure and Photosynthesis

Lesson 19: Tobacco, Alcohol and Drugs

Lesson 20: Pollution

A LESSON RECORD FORM MUST BE COMPLETED FOR EVERY LESSON SUBMITTED FOR CORRECTION, AS ILLUSTRATED BELOW

A Lesson Record form with the **correct** label attached **must** be enclosed with **every lesson** submitted for correction, as illustrated below.

Correct use of these labels will ensure prompt processing and grading of your lessons.

The enclosed **Lesson Labels** must be checked for spelling and address details.

Please advise the Alberta Correspondence School promptly of any changes in name, address, school, or any other details and we will issue a revised set of labels. Your file number is permanently assigned and **must** be included on all correspondence with the Alberta Correspondence School. If the proper label and Lesson Record Form is not attached to each lesson as indicated it will delay your lessons being processed and credited to you.

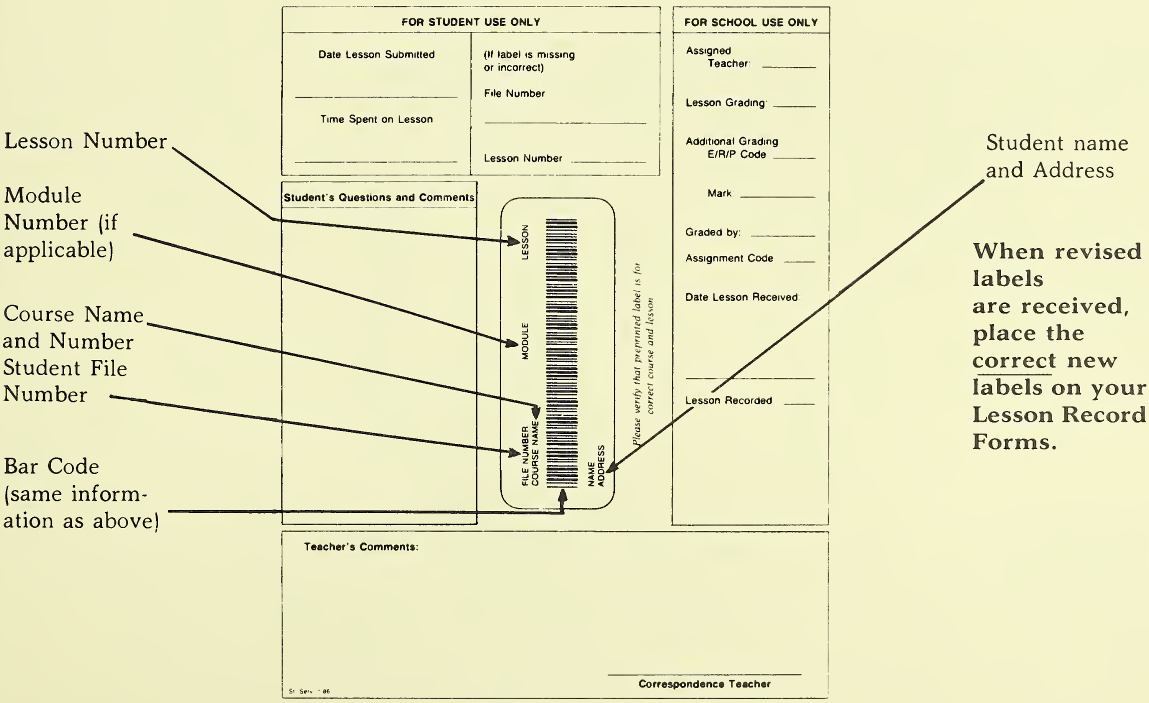
Lesson labels are to be attached to the **lesson record forms** in the space provided for student name and address.

Check carefully to ensure that the **subject name, module number** and **lesson number** on each label corresponds exactly with the lesson you are submitting.

Labels are to be **peeled** off waxed backing paper and **stuck** on the lesson record form.

Only **one** label is to be placed on each lesson.

LESSON RECORD FORM



FOR STUDENT USE ONLY

Date Lesson Submitted ________

Time Spent on Lesson ________

(If label is missing or incorrect)

File Number ________

Lesson Number ________

Student's Questions and Comments

Please verify that preprinted label is for correct course and lesson

FOR SCHOOL USE ONLY

Assigned Teacher: ________

Lesson Grading: ________

Additional Grading E/R/P Code ________

Mark: ________

Graded by: ________

Assignment Code ________

Date Lesson Received ________

Lesson Recorded ________

Teacher's Comments:

____
Correspondence Teacher

St. Serv. 86

When revised labels are received, place the correct new labels on your Lesson Record Forms.

DO NOT MARK OR COVER BAR CODING.

CHANGE OF ADDRESS

If the address on your lesson record form differs from the address you supplied on your registration application, please explain. Indicate whether the different address is your home, school, temporary or permanent change of address.

LESSON RECORD FORM

3230 Biology 30
Revised 03/89

FOR STUDENT USE ONLY

Date Lesson Submitted ____________________

Time Spent on Lesson ____________________

(If label is missing
or incorrect)

File Number ____________________

Lesson Number ____________

FOR SCHOOL USE ONLY

Assigned Teacher: ________

Lesson Grading: ______

Additional Grading E/R/P Code: ______

Mark: __________

Graded by: ________

Assignment Code: _____

Date Lesson Received:

____

Lesson Recorded _____

Student's Questions and Comments

Apply Lesson Label Here

Name
Address
Postal Code

Please verify that preprinted label is for correct course and lesson.

Teacher's Comments:

____
Correspondence Teacher

St. Serv. 1-86

ALBERTA CORRESPONDENCE SCHOOL

MAILING INSTRUCTIONS FOR CORRESPONDENCE LESSONS

1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

First Class

Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

SPECIFIC LEARNING OBJECTIVES

If you conscientiously complete the prescribed work contained in this lesson you will be capable of carrying out the following correctly:

1. **Comprehend** the importance of the contributions of early scientists to the field of biology and cytology today.
2. **Identify** the scientists responsible for discovery of cells.
3. **Identify** the scientists who established the cell theory.
4. **List** the three principles composing the cell theory.
5. **List** three developments in microscopy that have increased scientific knowledge of the cell.
6. **Identify and convert** from one form to another units of measurement suitable for use in microscopy.
7. **List** four components of a cell that are not clearly visible through a light microscope.
8. **Distinguish** between resolving power and magnification.
9. **Specify** the range in size of cells as well as the diameter of the average cell.
10. **Explain** why cell size and metabolic activity are related.
11. **Identify** the factors believed to affect cell size and activity.
12. **Explain** the process of centrifugation and the order in which different cell fragments settle out.
13. **State** three differences and three similarities that exist between a typical plant cell and a typical animal cell.
14. **Identify** three main regions common to all cells.
15. **Identify** the following cell structures from a diagram or a written description of each:
    - (a) nucleus
    - (b) nucleolus
    - (c) nucleoplasm
    - (d) chromosomes
    - (e) chromatin
    - (f) nuclear membrane
    - (g) cytoplasm
    - (h) endoplasmic reticulum
    - (i) Golgi apparatus
    - (j) ribosomes
    - (k) mitochondria
    - (l) lysosomes
    - (m) microfilaments
    - (n) microtubules
    - (o) centrosome (centrioles)
    - (p) chloroplast
    - (q) plastids
    - (r) vacuoles
    - (s) cell membrane
    - (t) cilia
    - (u) flagella

16. **Identify** the major functions of the structures listed in Objective 15.

17. **Distinguish** between a permeable membrane, a semipermeable membrane and an impermeable membrane.

18. **List** two passive processes and three active processes that move substances into a cell.

19. **Distinguish** between protoplasm, cytoplasm and nucleoplasm.

20. **Understand** the significance of the genes to the characteristics of a cell.

The Structure and Function of Cells

Introduction

Welcome to the first lesson of the Biology 30 course. If you haven't read the course "Introduction" preceding Lesson 1, please do so, then return to this lesson.

In Lesson 1 you will be studying cells. All living things are made of cells and cell products. This is important because the numerous activities essential to life occur at the cellular level. The major concepts you will be introduced to include:

1. a historical perspective of the events and individuals responsible for establishing current knowledge of the cell.
2. the cell theory.
3. cell measurement.
4. factors affecting the size and shape of cells.
5. equipment and techniques used for studying cells.
6. the nature of protoplasm, cytoplasm and nucleoplasm.
7. the structure and function of organelles that make up the cell.

N.B. - Throughout your readings, if you do not understand a term, look it up in the glossary pages 497 to 507 of your text or consult a dictionary.

Early Observations of the Cell

It is now well documented that all living things are composed of cells and cell products. Throughout most of history this knowledge did not exist. Most cells are very small, too small to be seen by the unaided eye. Consequently people were not aware of the existence of cells because they were not able to see them.

The discovery of cells had to await the invention of the light microscope. At some point in human history it was discovered that bits of glass of a particular shape had the ability to magnify objects viewed through them. In essence the magnifying glass had been discovered. Lenses are known to have been made and used for at least two thousand years. However, their use as magnifiers in the observation of natural things did not become common until the 1600s.

Anton Von Leeuwenhoek, a Dutch cloth merchant, was among the first amateur naturalists to discover and study cells. Using a single lens microscope of his own design and making, he (in 1674) was first to observe single-celled organisms in rainwater, pond and well water. These organisms which he called "very little animalcules" we know today as bacteria and protozoa. Over the next fifty years Leeuwenhoek went on to make many important observations and discoveries which he submitted in numerous informal letters to the Royal Society of London for publication to the public. Included were his observations of bacteria, protozoa, yeast, sperm cells and red blood cells. Leeuwenhoek's observations helped refute the commonly held doctrine of spontaneous generation—that low forms of animal life (fleas, weevils, grubs, maggots, mussels, eels, etc.) would arise spontaneously from nonliving matter. e.g. Maggots arise from rotting flesh and fleas are produced from sand. From his observations of living things he concluded that they are the products of the reproductive behavior of their parents.

Though Leeuwenhoek observed many types of cells, he did not recognize the significance of his observations in terms of the general structure of living things. The cellular nature of living things would continue to remain a secret for the next 150 years.

Another early scientist who shed some light on the nature of cells was the Englishman, Robert Hooke. Technological advances in microscope construction led to the development of the two lens or compound microscope. This instrument gave superior magnification and clarity of image compared to its single lensed predecessor. Hooke used this instrument to make the first published observations (1665) of thin slices of cork. He noted that cork appeared to consist of a mass of tiny cavities, each cavity surrounded by walls. He likened them to the cells of a honeycomb, calling the cavities **cells**. Thus, Hooke coined the term that is used to this day.

Hooke's observations of cells were somewhat incomplete. He did not realize that an important region of each cell, the living contents, was missing. The living contents of these cells had died and disappeared. All that remained for him to see were the cell walls. Perhaps if Hooke had made further observations of either plant or animal cells he would have discovered their living contents.

The Cell Theory

Following the discoveries of Leeuwenhoek and Hooke, knowledge of the structure of the cells progressed rather slowly for the next 150 years. Improvements in the microscope were also taking place at this time. Higher magnification without aberration and better methods of illumination enabled scientists to probe further into the cell.

Significant breakthroughs in knowledge of the cell began to take place in the 1800's as scientists from many different countries began making new discoveries. In 1835 the French biologist Félix Dujardin ((1801-1860) viewed cells through a microscope and discovered their living contents, known as **protoplasm**. In 1838 the German botanist, Matthias Schleiden, after observing a wide variety of plant structures concluded that they were all made of cells. The German zoologist Theodor Schwann noted that all animals are composed of cells. In his book of 1839 he gave credit to the discoveries of Schleiden and expanded on them to state that all organisms, both plants and animals, are composed of cells and that some organisms are unicellular while others are multicellular. In 1855 another German biologist, Rudolph Virchow concluded from his investigations with the microscope that cells only come from cells of the same type by reproduction. Thus, the work of these and many other nineteenth century scientists helped establish the cell theory as it presently exists. The theory states that:

1. All organisms are made of cells and cell products (e.g. hair, bone, wood, etc.)
2. The cell is the unit of structure and function for living organisms.
3. All cells originate from other cells by reproduction.

Note that the cell theory is not so much a theory in the conventional sense of the term as it is an observable fact of nature.

Biologists now agree that the cell is the basic unit of all living things and that all life appears to be based on cells and their products. The cell is therefore considered the fundamental structural and functional unit of all living matter. Cells are sometimes broken apart in order to be studied. Researchers have discovered that the cell fragments are able to carry on many of their activities independently for some time. "Life" activities such as utilizing sugar and oxygen and the formation of new molecules may be carried out independently but not indefinitely by the cell fragments. Based on this evidence, cytologists have concluded that a single cell is the simplest unit of living matter that can carry out life by itself.

Cell Measurement

Cells vary a lot in size. The largest cells, such as the yolk of a goose egg, are easily seen and may measure up to 2 cm in diameter. Most cells and their parts are much smaller than this and can only be seen and measured under a microscope.

Due to the microscopic nature of most cells and their parts, the metre, centimetre and millimetre are much too large to use as units of measurement. Units of measurement that are more suitable include the micrometre and the nanometre.

The micrometre, which is represented by the symbol μm, is 10^{-6} metres (0.000 001 m) or 10^{-3} millimetres (0.001 mm). In other words, there are a hundred thousand micrometres in one metre or 1000 micrometres in one millimetre. A millimetre is roughly the thickness of a dime, consequently it can be seen that a micrometre is a very small unit of measure. A human cheek cell measures 60 μm in length, whereas a red blood cell only has a diameter of 7.5 μm. Under ordinary circumstances the unaided human eye can see objects no smaller than 100 μm, thus necessitating the use of a microscope to study cells.

If cells are small, the component parts of a cell (organelles) are much smaller. Indeed many organelles are so small they cannot be seen through a light microscope. Any object smaller than 0.25 μm cannot be seen with a light microscope. Until the electron microscope was invented, the details of cellular structure such as the cell membrane, ribosomes, endoplasmic reticulum, centrioles, etc. had never been revealed because these structures were so small.

An equally small unit of measure, the nanometre is used for describing these structures. A nanometre is 10^{-9} metres of 0.001 μm. In other words it takes a thousand nanometres (nm) to make one micrometre (μm). A few examples of organelles measured in nanometres are the cell membrane (7.5 to 10 nm in thickness), the ribosomes (15 nm in diameter), and mitochondria (rod-shaped or spherical structures ranging in size from 200 to 500 nm).

READ

Turn to page 18 of your text and read the section entitled "Microscopy and the Concept of Size."

Note that the term ''micron'' is an obsolete metric term that has been displaced by the term micrometre.

Resolution and resolving power are terms used in microscopy. These terms refer to the ability to produce separate images from two objects that lie very close to each other. Light from the two objects tends to fall together on the eye thus the two objects appear as one. The following occurence illustrates resolution (resolving power). You may have observed that at night when a car approaches you, but is still very distant, the light from the two headlights appears as one. As the car gets closer, you will finally be able to distinguish the two headlights. If you took a good pair of binoculars and looked at the distant car, you would be able to see two distinct headlights instead of one because of the magnifiying power of the binoculars.

Under normal circumstances the unaided human eye is only able to distinguish between objects that are further apart than 0.1 millimetres (100 μm). Two objects closer together than this appear as one. The most powerful light microscopes increase the resolving power of the eye by roughly 400 times. The limits of resolution with the light microscope are 250 nm. This is why it was necessary for scientists to invent the electron microscope before studies of the smallest cell structures could be made. The electron microscope gives resolutions one hundred times that of the best light microscopes and magnifications greater than 100,000 X (times).

Cell Size and Shape

Cells come in a great variety of sizes and shapes. The largest cells such as the yolks of bird eggs achieve diameters of two to three centimetres. However, most cells are much smaller, most having diameters between 0.5 and 15 μm. The human ovum is just under 0.1 mm whereas red blood cells are only 7.5 μm in diameter. The mycoplasmas, a type of microorganism, are the smallest cells known at 0.1 μm.

The size and shape of a cell are usually a reflection of the function of the cell. Egg cells are large as a result of the food they store for the developing embryo. Nerve cells may have extensions up to 90 cm in length for the rapid transmission of impulses over long distances. Muscle cells are elongated in the direction in which they contract. When cells are packed together in masses they have a polyhedron shape (a body with many faces) which permits the cells to be closely packed without large spaces between them. The polyhedron shape is characteristic of cells from organs such as the liver.

Scientists have researched factors limiting the size of cells. One such factor is the cell surface area to volume ratio. As a sphere (many cells are more or less spherical) gets larger, its surface area increases at a much slower rate than its volume does. The surface area increases as the square of the radius while volume increases as the cube of the radius. This is significant because the surface area of the cell, represented by the cell membrane, does not increase at as fast a rate as the volume of the cell represented by the living contents (protoplasm). All material necessary to support life (e.g. oxygen, glucose, amino acids, fatty acids, etc.) must enter through the cell membrane. Carbon dioxide and other metabolic wastes must leave through the cell membrane. There must be enough cell membrane surface area to meet the metabolic needs of the cytoplasm inside the cell. The limits of cell size are met when the surface area can no longer provide for the entrance of enough raw materials or the exit of wastes to meet the metabolic needs of the protoplasm contained by the cell membrane. The rate of metabolism (the chemical processes occuring within a cell) will thus affect cell size. Cells with high rates of metabolism will have to be smaller than those with low rates in order to maintain the proper surface to volume ratio. Human liver cells are very active metabolically and are very small compared to many other cell types. Shape can also be a factor affecting surface area to volume ratio. Long thin cells or disc shaped cells have a much higher surface area to volume ratio than spherical cells and consequently they can be much larger. Human nerve cells must be both large and metabolically active. These cells solve the surface area to volume ratio problem by being extremely long (as long as 90 centimetres) and very thin. When the limits of cell size imposed by metabolic activity and surface area are reached, a cell must either stop growing or divide.

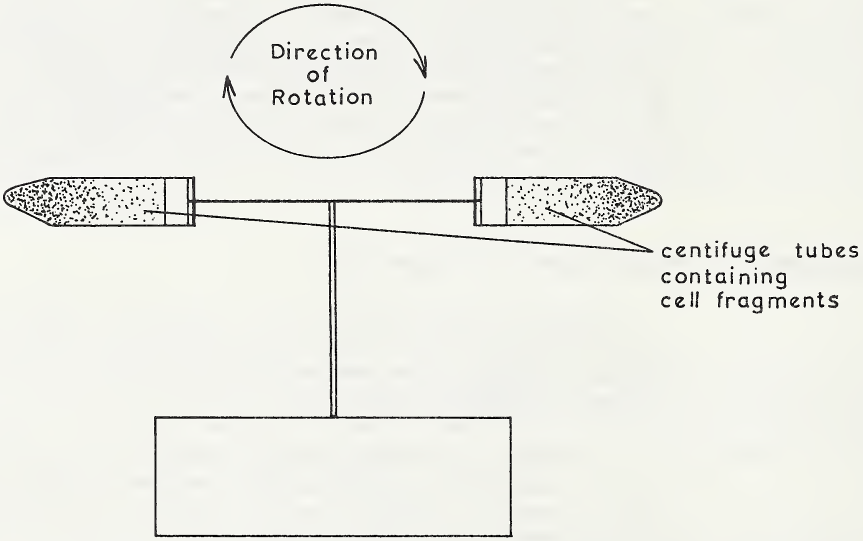
Cell size may also be linked to factors other than surface area to volume ratio. One such factor is physical support. Plant cells are supported by a rigid cellulose cell wall while animal cells in general lack this type of physical support. In fact this lack of physical support may be one reason why animal cells are generally smaller than plant cells. Another reason may be that animal cells tend to be more active metabolically than plant cells. Scientists have also speculated that there is a limit to the amount of cytoplasm that a nucleus may control. Research is still going on in an effort to determine the factors that limit cell size.

Equipment and Techniques Used for Studying Cells

Scientists have approached the study of cells from two different points of view. At first scientists used direct observation of cells as the primary method of investigation. Later on chemical analysis of cell contents was added. Let's take a closer look at the developments that have taken place in both areas.

As was noted earlier the first tool used to observe cells was the single lens microscope, basically a high powered magnifying glass. Development of the compound microscope (two lenses) increased the magnifying and resolving power of the microscope. Improvements in the illumination of specimens for microscopes also occurred. It was discovered that shining light through a thin slice of specimen revealed greater detail than reflecting light off the surface of the specimen. The need for very thin slices of cells led to the development of the microtome, a meat cutter-like device than can make slices 5 to 15 μm thick. As most parts of cells are quite transparent, they are difficult to see when viewed through a microscope. Scientists discovered that certain dyes could be used to differentially stain various parts of the cell. Based on their chemical composition different cell parts are stained different colors by different dyes. This greatly improved the detail of structures that could be seen in the cell. Light microscopes can only be used to determine the details of structures larger than 250 nm due to their limited resolving power. Consequently further knowledge of cell structure had to await the development of the electon microscope. The electron microscope is capable of very high magnification (20,000,000 X) and is capable of resolving objects down to 0.25 nm. Much of the detail of the smallest organelles in a cell is due to discoveries made with the electron microscope.

Other scientists have studied the chemical nature of cells. One of the techniques used is called centrifugation. Cells are broken open (homogenized) by various mechanical means to release their intracellular structures. A high speed centrifuge (ultracentrifuge) is then used to spin the cell contents into separate layers. The centrifuge tube, into which the cell contents have been placed, is spun in a circle at speeds as high as 70,000 revolutions per minute. The heaviest cell fragments, the nuclei, are driven to the end of the tube farthest from the center of the circle. The lightest components (cell fluid) remain at the end of the centrifuge tube closest to the center of the circle.



Tubes are spun to separate cell fragments into different layers.

Figure 1: Centrifugation

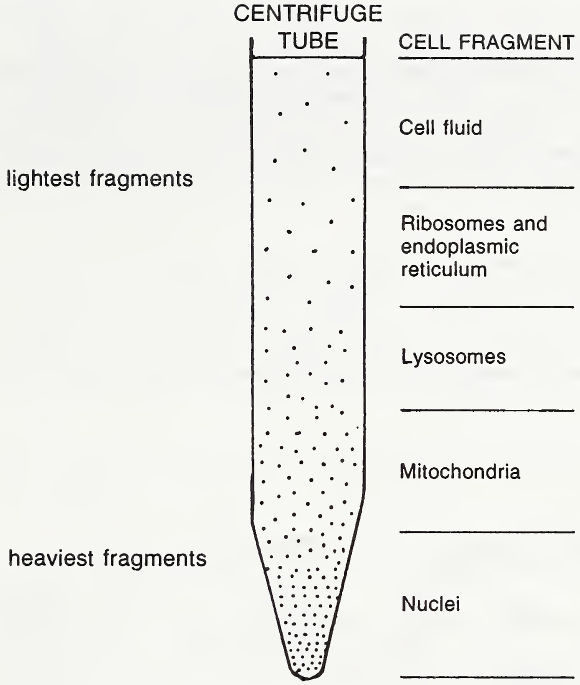


Figure 2: How Cell Fragments Separate After Centrifugation

Once the cell fragments have been separated by centrifugation each type can be used for scientific testing. They may be examined under an electron microscope or used for biochemical tests.

Radioisotopes have also been used as tracer elements to determine which organelle a particular chemical reaction is occurring in. Scientists use the isotopes to follow different chemical reactions through a cell and relate each change to a specific structure.

The techniques mentioned have allowed scientists to discover a great deal about how cells are organized and how they function. Much remains to be learned, consequently the research continues.

Plant and Animal Cells

In order to better understand the cell one must look at the various components making up a cell and how they function. But which type of cell should be looked at? There are many types of cells. Mesophyll cells, epidermal cells, guard cells and xylem are a few of the different cell types found in plants. Animals also show the same diversity of cell type. Generally, it can be stated that cells vary greatly in structure and function. Consequently there is no such thing as a typical cell. However, cells also have many features in common.

Most cells consist of three general regions; organelles, cytoplasm and an outer covering. Because animal cells tend to resemble themselves more than plant cells and vice versa, it is convenient to think of there being a typical animal and plant cell. Now, take a look at each one. You will note that each of these cells appear quite different from the other. Note that structures common to both cells are shown in the center column. Structures that differ between cells are labelled without using square brackets around the word.

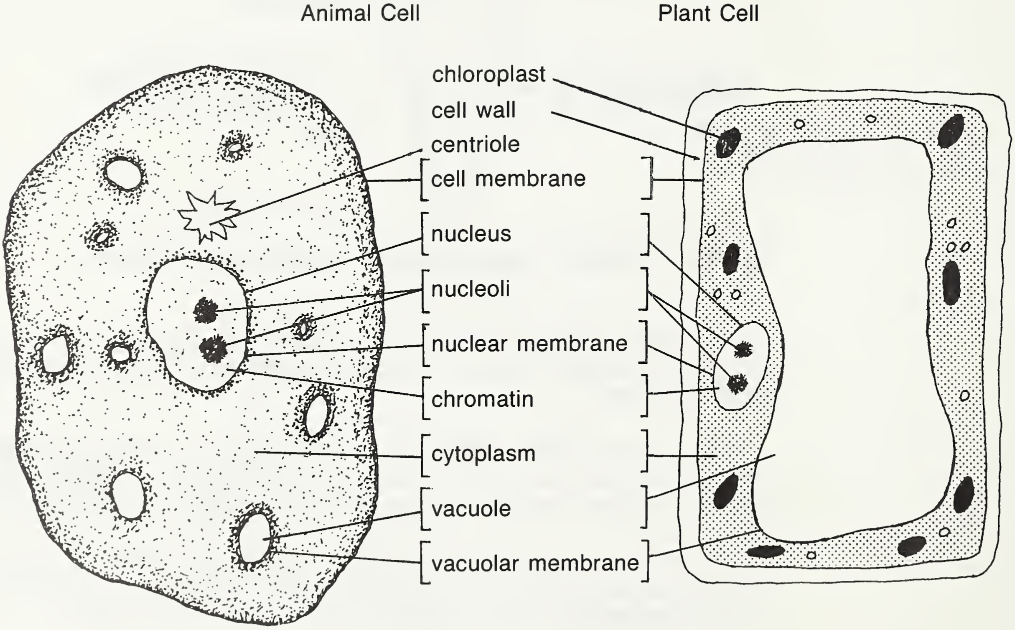


Figure 3: **Plant and Animal Cells**

Plant and animal cells are generally considered to differ in the following ways.

1. Plant cells and their vacuoles are usually many times larger than animal cells and their vacuoles. N.B. - The animal cell in the diagram is only drawn to the same size as the plant cell for convenience of representing internal structures.

2. Plant cells always have a semirigid nonliving cell wall outside of the cell membrane. Animal cells lack a cell wall. Their outer surface is the cell membrane.

3. Some plant cells are able to manufacture their own food by the process of photosynthesis. Those plant cells that are able to do this have a green substance called chlorophyll localized within organelles called chloroplasts. Chloroplasts are present in many plant cells but lacking in all animal cells.

4. The centriole is present in all animal cells but lacking in advanced plant cells.

Exercise 1

Circle your choice - True or False.

1. With few exceptions, individual cells cannot be observed with the unaided eye. T F
2. The first recorded observations of single-celled organisms were made by Anton von Leeuwenhoek. T F
3. According to the doctrine of spontaneous generation, living things originate only through reproduction from other living things. T F
4. Robert Hooke was responsible for discovering the living contents of cells. T F
5. There are one thousand micrometres in a millimetre. T F
6. Details of objects smaller than 0.25 μm cannot be seen through the most powerful light microscopes. T F
7. The size of cells is related to the movement of materials into and out of cells from the environment. T F
8. Cell fragments of specific types can be separated from each other by using a microtome. T F
9. Most cells resemble each other in that they have a cell membrane, cytoplasm and a nucleus. T F

Select the best answer or answers to each question.

______ 10. Which of the following would not be considered a primary tool of the biologist?

(a) light microscopes
(b) microtomes
(c) centrifuges
(d) telescopes

______ 11. The cell theory states that

(a) the cell is the unit of structure for living organisms.
(b) all organisms are made of cells.
(c) all cells originate from other living cells.
(d) all the above.

_____ 12. The unit of measurement that is most suitable for describing most cellular structures is the

(a) centimetre.
(b) millimetre.
(c) micrometre.
(d) micron.

_____ 13. Details of organelles such as the cell membrane and mitochondria can be seen through the

(a) single lens microscope.
(b) compound microscope.
(c) electron microscope.
(d) all the above.

_____ 14. Cells that have a high surface area to volume ratio

(a) are very large.
(b) have a large nucleus.
(c) are never long and thin.
(d) may be very metabolically active.

_____ 15. The cell fragments that would start to separate out first during centrifugation would be the

(a) nuclei.
(b) lysosomes.
(c) cell fluid.
(d) mitochondria.

Please check your answers with those given on page 31.

The Generalized Animal Cell

Continue the study of cells by taking an in-depth look at a generalized animal cell. As many different types of animal cells exist, a generalized animal cell should exhibit all the characteristics of these different cells. Note that a generalized animal cell does not really exist as it is a composite developed from characteristics present in all types of animal cells.

For convenience of study, the generalized cell can be divided into three regions:

1. The **plasma (cell) membrane** is the outer boundary of the cell that separates the internal structure of the cell from extracellular (outside the cell) substances of the external environment.
2. The **cytoplasm** is a complex semifluid substance lying between the cell membrane and nucleus.
3. The **organelles** are cellular structures that perform specific functions for the cell. e.g. nucleus, ribosomes, endoplasmic reticulum, etc. All organelles with the exception of the centriole, ribosomes, microfilaments and microtubules are bound by unit membranes.

Note these regions in the diagram that follows. The diagram is an illustrator's representation of the details of cell structure developed from photographs (micrographs) made with an electron microscope. Note that size comparisons between the different organelles should not be made as they are not all drawn to the same scale. The shape of each organelle accurately reflects what is known from electron micrographs.

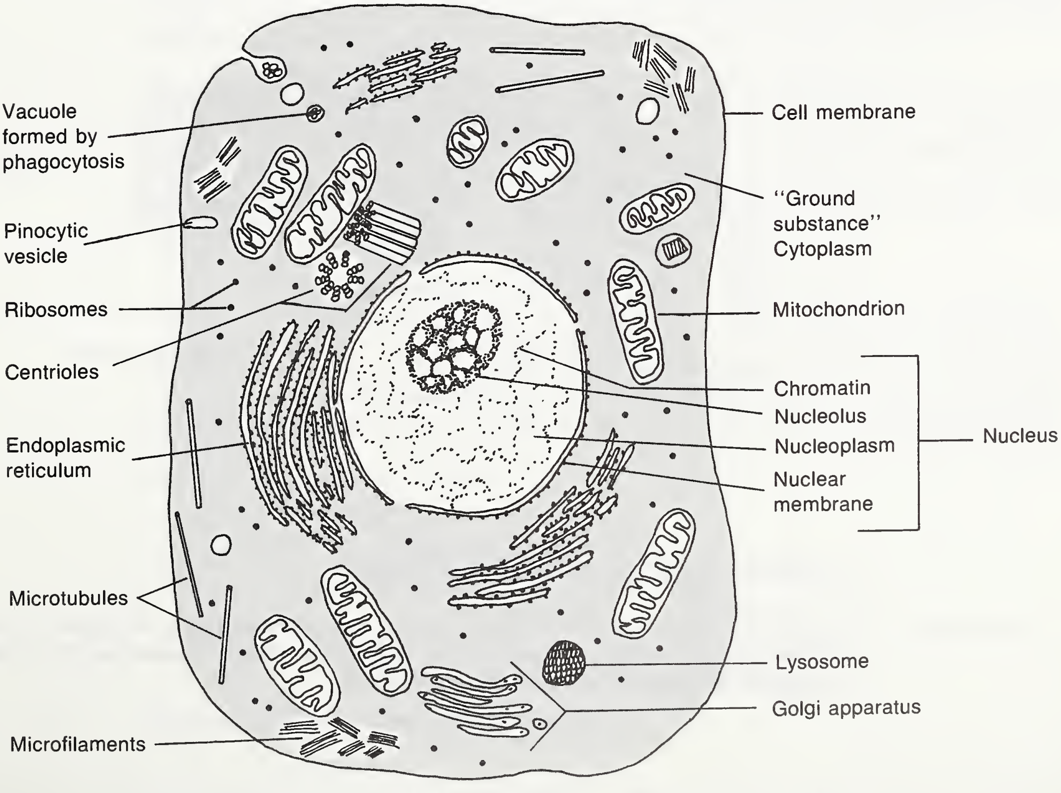


Figure 4: Generalized animal cell based on electron microscopy.

The Cell (Plasma) Membrane

This membrane is interchangeably referred to as the cell membrane, plasma membrane and less often the unit membrane. It is the thin elastic outer boundary that surrounds the protoplasm of a cell. It is so thin in fact (7.5 to 10 nm) that it cannot be seen with a light microscope. Before the discovery of the electron microscope its presence could only be implied. For instance, when a cell was punctured by a microneedle, the contents would flow out. When the margin of a cell is pushed on, it will indent, much as a balloon would, thus indicating the presence of some sort of membrane or barrier.

The electron microscope, microtechniques for obtaining cell membranes, physical studies and chemical studies of the cell membrane have done much to reveal most of the details of its structure. Chemical analysis of the membrane indicates it to be mostly protein (50 to 70% by weight) with phospholipid, a molecule consisting of a phosphate head and two fatty acid tails, being next most abundant. The phospholipid molecules are arranged in a double layer, with the phosphate heads on the inner and outer surfaces of the membrane and the lipid (fatty acid) tails to the inside of the membrane. **See Figure 5**.

The proteins associated with the membrane can be grouped into two categories. **Integral proteins** are imbedded into the layers of phospholipid. Some extend in from one or the other surfaces only as far as the lipid tails while others extend right through the double layer. The other group of proteins are the **peripheral proteins**. They are loosely attached to the surface of the membrane. Figure 5 illustrates the arrangement of these different molecules.

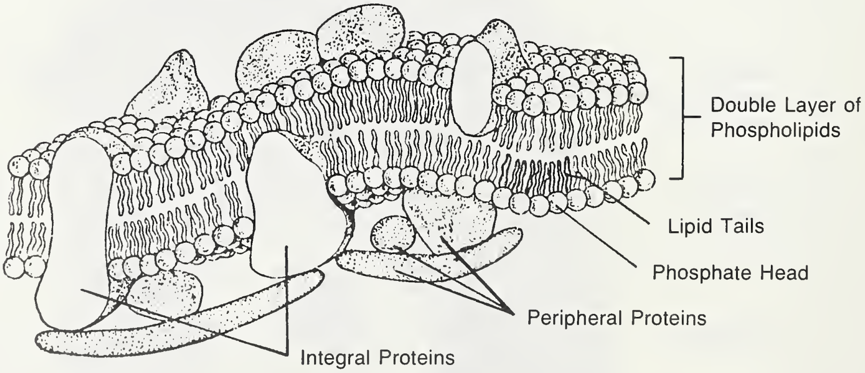


Figure 5: **Structure of the Cell Membrane**

N.B. - The description of the structure of the cell membrane on pages 19 and 20 of the text is not entirely accurate. The description above is more accurate because it is based on more recent scientific evidence.

The cell membrane carries out a variety of functions for the cell. First, it is a barrier between the inside of the cell and the external environment. It protects the inner parts of the cell from mechanical damage. Mechanically, the membrane behaves more or less like a flexible barrier similar to the skin covering the human body. Though very thin, the plasma membrane is quite strong and can withstand abrasions and wear. Researchers have discovered that when damaged, the membrane is able to repair itself if calcium ions are present.

The membrane must also protect the cell from chemical damage. All cells are surrounded by a chemical environment — the extracellular fluid outside the cell. Under normal circumstances materials constantly move into and out of the cell. The delicate balancing of materials, called homeostasis, is believed to be controlled by the cell membrane itself. Any major shift in the concentrations of materials inside or outside the cell could result in damage or even death of the cell.

The second function of the cell membrane is to control what materials are able to enter and leave the cell. Some materials are able to enter quite easily while others move through the cell membrane with greater difficulty. A membrane that allows materials to pass through it freely is said to be **permeable**. Since the cell membrane controls which substances are able to enter and leave a cell as well as the rate at which they do so, it is referred to as a **selectively permeable, semipermeable** or **differentially permeable** membrane. (All three terms are interchangeable.)

The mechanisms by which the cell membrane controls the movement of materials in and out of the cell fall into two categories, passive processes and active processes.

The **passive processes** move substances across the cell membrane without assistance from the cell. The substances move on their own along a concentration gradient from a region of higher concentration to a region of lower concentration. The passive processes include **diffusion** and **osmosis**. These processes will be discussed further in Lesson 2.

The **active processes** require energy from the cell to move substances across the cell membrane into the cell. The energy is required to move the substances against the concentration gradient. Active processes include **active transport, pinocytosis** and **phagocytosis**. In active transport, substances such as ions are moved across the cell membrane from a region of lower concentration to a region of higher concentration. Energy in the form of ATP is used to move substances against the concentration gradient.

The plasma membrane can also form microscopic channels or inpocketings known as pinocytic vesicles, into the interior of the cell. In the process of pinocytosis, liquids enter and flow along these channels and then are pinched off in the cytoplasm forming vacuoles enclosed by the cell membrane. Another process called phagocytosis enables a cell to engulf large solid particles by flowing around them. These particles are too large to enter the cell by diffusion or active transport. The particle is encased inside the cell membrane in a vacuole that pinches off into the cytoplasm. The engulfed particles are digested and utilized as nutrients for growth and repair.

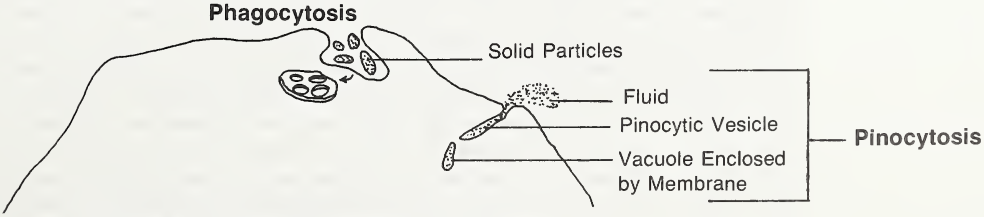


Figure 6: Phagocytosis and Pinocytosis

Other functions of the cell membrane include making contact with other cells and providing receptor sites (the site where a substance can attach to the cell membrane) for substances such as enzymes, hormones and antibodies.

N.B. - Membranes are also present inside the cell as part of the structure of the organelles. These membranes are similar though not always identical in chemical composition and physical organization to the outer cell membrane. For instance, different types and amounts of protein may be present in the phospholipid double layer. Different membranes have different functions. These differences are reflected in the chemical and physical nature of the membrane.

Cell Coatings

The cell membrane does not make up the outer covering of most cells. The cell usually secretes an exterior coating over the cell membrane. Many animal cells are coated by a substance composed of protein and polysaccharides. This substance serves to bind the cells together. Proteins such as collagen and elastin may also be present to assist in binding the cells together.

Only plant cells are surrounded by a cell wall. It is a fairly rigid structure of nonliving material that surrounds the cell membrane in plant cells. The cell wall is made of cellulose secreted by the cell. Because the cell wall is porous, molecules pass through it unhindered. It does not control which substances pass through it.

Protoplasm, Cytoplasm and Nucleoplasm

The term **protoplasm** was coined by the French biologist Dujardin in the early 1800s. He used the term to refer to the living contents of the cell; the material that makes up the cell. It was believed that protoplasm was a uniform substance much the same from one cell to the next. Nowadays we know that there is no single material making up a cell. Living material is made up of many substances and structures, not just a single substance. Even though there is no single living substance, the term protoplasm is still useful when used to refer to the living contents of a cell. Today's generally accepted definition of protoplasm is the living contents of a cell. It includes the cell membrane but is usually taken to exclude large vacuoles, ingested materials and the cell wall of plant cells. Protoplasm is differentiated into two regions, the nucleus and cytoplasm.

The **cytoplasm** is the substance lying between the cell membrane and the nucleus in which the organelles are suspended. Different observers have described cytoplasm in a variety of ways. For example, it has been described as a thick, semitransparent, elastic fluid. Within the liquid ''ground substance'' are many dissolved and suspended materials. When analyzed chemically, the fluid part of the cytoplasm is found to contain a rich mixture of salts, proteins sugars, minerals and oils which supply the nutrients needed by the organelles for energy, repairs and growth. Wastes from metabolic activities are also present. In terms of percentage, results of chemical analysis of cytoplasm show about 80% water, 15% protein, 3% lipid (fat), 1% carbohydrate and 1% inorganic substances. The inorganic substances such as salts, and most carbohydrates dissolve readily in water, hence are present in solution. The organic compounds such as proteins, on the other hand, are present as colloids (small particles suspended in a liquid). They possess electrical charges that in effect repel each other thus remaining in suspension. You will recall that most of the chemical reactions in living organisms require water, hence it is in the cytoplasm that most of the reactions associated with the life processes occur. Furthermore, embedded in the cytoplasm are crystals of various kinds and the major organelles such as the endoplasmic reticulum, the ribosomes, the mitochondria, the Golgi apparatus (body), the lysosomes, pinocytic vesicles and in plant cells only, the chloroplasts. The functions of the cytoplasm are for the most part the functions of the organelles suspended in it.

Researchers have discovered that the cytoplasm may be either in a sol (liquid) or gel (jellylike) state at a particular time and in different parts of the cell. In the 'sol' state the organelles are spaced far apart in the fluid, while in the 'gel' state, the organelles are closer together in the jellylike cytoplasm.

Nucleoplasm is a gel-like fluid within the nucleus in which nucleoli and chromatin are suspended. It is bounded by the nuclear membrane.

The Organelles

Numerous chemical activities occur simultaneously in the cytoplasm of a cell. Yet there is little interference of one reaction with another. The reason for this, at least in part, lies in the fact that most organelles with the exception of the ribosomes, centrioles, microfilaments and microtubules are bounded by unit membranes and function as separate compartments. Functionally, organelles carry out specific roles in growth, repairs, maintenance and control.

The organelles range in size from the microscopically invisible ribosomes and endoplasmic reticulum to the barely visible mitochondria, Golgi apparatus, lysosomes and centrioles to the large vacuoles and nucleus. Note that in the diagram that follows none of the organelles are drawn in proportion to each other regarding size.

READ

Read pages 16 to 25 of your text then return to the readings in the lesson.

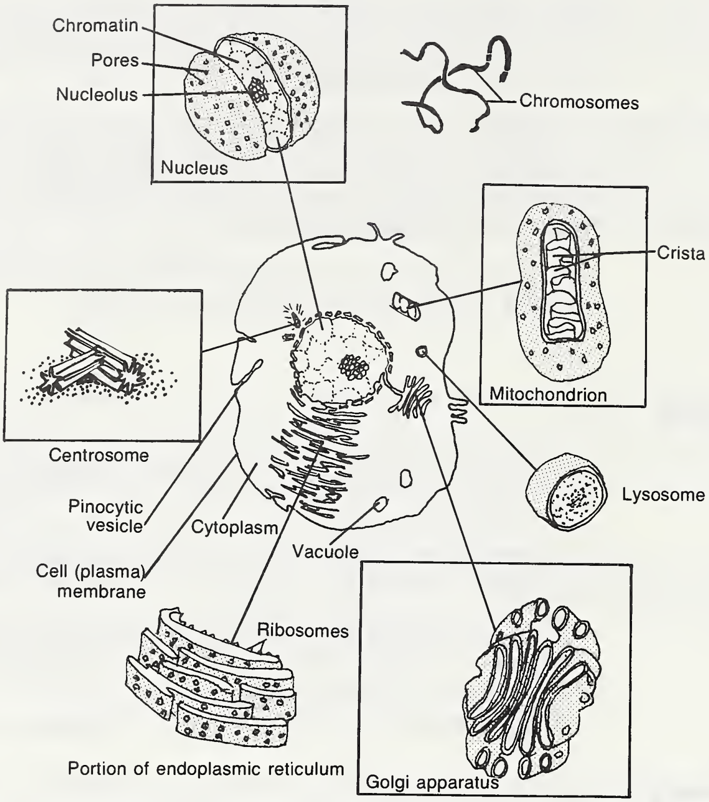


Figure 7: A Typical Animal Cell and Its Organelles

The Nucleus

The nucleus is usually the largest organelle in a cell. It is a spherical or oval body that can usually be found near the center of the cell. In some cells the nucleus moves about freely and may be found anywhere in the cell at any particular time.

The nucleus is the control center of a cell. It contains the hereditary factors that govern all the cell's activities as well as its structure. Scientists have been able to demonstrate the functional role of the nucleus. When the nucleus is removed from a cell, the cell remains alive but can only carry out its functions for a short period before dying. A cell without a nucleus is unable to grow or reproduce. Mature red blood cells, for example, lack nuclei. They carry out their chemical activities but are unable to grow or reproduce.

Each nucleus is surrounded by a double layered membrane (two unit membrane) known as the **nuclear envelope** or **nuclear membrane**. Chemical analysis has shown that the nuclear membrane is very similar in chemical composition to the cell membrane. This membrane serves to protect the nuclear material. It also controls what materials can enter and leave the nucleus. Very small pores located in the nuclear membrane allow the nucleus to communicate with the membranous network (the endoplasmic reticulum) that lies outside the nuclear membrane in the cytoplasm. Molecules are able to pass back and forth through the tiny pores.

There usually are three prominent features visible inside the nuclear membrane. First is the gel-like **nucleoplasm** that fills the nucleus. The next structure is the **nucleolus** (plural nucleoli). One or more of these structures are normally present in the nucleus of most cells. The actual number of nucleoli per nucleus varies for different cell types, and is believed to be directly related to the number of ribosomes required for the cell to function normally. Ribosomes are necessary for protein synthesis. During cell division the nucleoli disappear, reappearing following cell division when the two new cells are complete. Nucleoli may be very small or totally absent in cells which carry out limited protein synthesis such as egg cells and sperm cells. On the other hand, nerve cells, muscle cells and secretory cells generally possess large nucleoli.

The nucleoli are composed of protein, DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). The function of the nucleoli is the synthesis and storage of RNA and proteins. The nucleoli are also packed with minute granules similar to ribosomes. These ribosomal units eventually pass into the cytoplasm where they play a role in protein synthesis.

The final component of the nucleus is the hereditary or genetic material, DNA. When the cell is not dividing the hereditary material is present as a very elongated, threadlike mass referred to as **chromatin**. It is scattered throughout the nucleoplasm and is just barely visible under a light microscope. When a cell begins to divide, the nuclear membrane disappears and the chromatin strands form short, thick, rodlike, visible structures known as **chromosomes**. The chromosomes are unique in that they are able to duplicate themselves so that when the cell divides both new cells will have complete sets of chromosomes. Chemical analysis indicates that the chromosomes are composed of DNA and protein.

The chromosomes carry the genetic information in the DNA that is responsible for controlling the structure and function of the cell. A gene is a segment of the DNA of a chromosome that is responsible for a particular characteristic or trait. The genes of a chromsome are in essence the blueprints for all the characteristics of the cell. All inherited characteristics and cellular activities are controlled by the genes. It is the genes that are of tremendous significance to researchers in fields such as medicine, dentistry, genetic engineering and in the ever increasing efforts for the prevention, management and cure of inherited diseases.

See the following diagram indicating the structure of the nucleus.

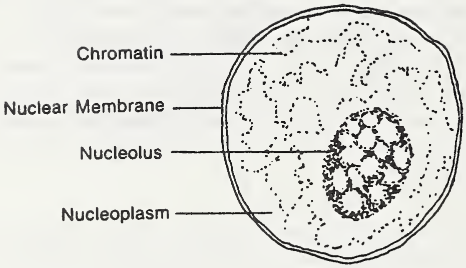


Figure 8: The Cell Nucleus

The Mitochondria

These microscopic organelles can be very numerous in a cell; up to 2500 in the liver cells of rats. They are granular, spherical, rod-shaped or filamentous structures that range in size from about 0.5 μm in width or diameter to 10 μm in length. The electron microscope reveals the basic structure of a mitochondrion (singular). It is bound on the outside by a double membrane that contains the dense matrix. The outer membrane provides a smooth continuous outer surface for the mitochondrion while the inner membrane has folds called **cristae** that project into the matrix. A large number of different kinds of enzymes are bound to the surface of the cristae.

Mitochondria Function as the ''power houses of the cell,'' providing the energy required for all cellular activities. Enzymes present in the cristae are used to oxidize food substances within the cell by the process of respiration. In respiration, glucose ($C_6H_{12}0_6$) in the presence of oxygen (0_2) is broken down to CO_2 and H_20 to release 36 ATP (adenosine triphosphate) of energy. It has been shown that active cells such as muscle cells, nerve cells and liver cells possess a high concentration of mitochondria due to their high energy requirements.

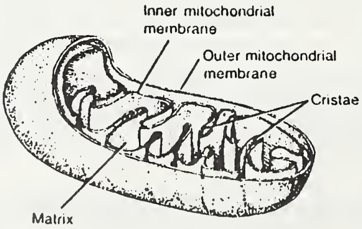


Figure 9: A mitochondrion with its double layered membrane.

Exercise 2

Match the term in the left-hand column with the appropriate definition or explanation in the right-hand column.

1. ______ cytoplasm
2. ______ nutrients
3. ______ inorganic substances and carbohydrates
4. ______ 'sol' and 'gel' state at different times at different locations in the cell
5. ______ chromosomes
6. ______ organic compounds
7. ______ the nucleus

(a) Substance comprising all the material located between the nucleus and the plasma membrane.

(b) Needed by the organelles for energy, repair and growth.

(c) Present in solution in the cytoplasm.

(d) These are unique in that they possess the ability to reproduce themselves.

(e) Provides the necessary control over cell structure.

(f) Present in the cytoplasm as colloids hence possess electrical charges that repel each other.

(g) The cytoplasm.

(h) The most abundant organic compound in the living cell.

8. List four (4) of the major organelles found embedded in the cytoplasm of cells.

(a) ______________________________

(b) ______________________________

(c) ______________________________

(d) ______________________________

9. List three (3) basic components of the nucleus lying within the nuclear membrane.

(a) ______________________________

(b) ______________________________

(c) ______________________________

10. What is the role of the nucleolus in cells?

____

11. What are cristae?

____

Circle your choice - True or False.

12. The nucleus is usually located near the centre of the cell. T F

13. Cells that contain a nucleus are able to grow and reproduce. T F

14. Very active body cells such as those of the liver, nerve cells and muscle cells have a high concentration of mitochondria. T F

15. The nucleus is sometimes termed the ''powerhouse'' of the cell. T F

Select the best answer or answers to each question.

______ 16. Under the light microscope the cell membrane
(a) is invisible.
(b) is visible.
(c) appears as a double layered unit.
(d) is conspicuous.

______ 17. Which of the following controls material entering and leaving the cell?

(a) the cell wall
(b) osmosis
(c) the cell membrane
(d) the mitochondria

______ 18. Which of the following processes enables a cell to engulf large particles lying near the cell membrane?

(a) pinocytosis
(b) phagocytosis
(c) osmosis
(d) active transport

______ 19. A passive process by which materials may enter a cell is

(a) diffusion.
(b) pinocytosis.
(c) phagocytosis.
(d) active transport.

Please check your answers with those given on page 31.

The Endoplasmic Reticulum and Ribosomes

The endoplasmic reticulum consists of a system of narrow cavities of varying shapes throughout the cytoplasm. The cavities are enclosed by membranes similar in structure to other membranes within the cell. The narrow cavities surrounded by membranes form a network of channels extending throughout the cytoplasm. The membranes of the endoplasmic reticulum are connected to the nuclear membrane, the Golgi apparatus, the cell membrane at the surface of the cell, as well as other organelles.

Two types of endoplasmic reticulum are distinguished on the basis of its association with ribosomes. **Rough endoplasmic reticulum** has numerous ribosomes attached to the outer surface of its membranes — the surface that is in contact with the cytoplasm. **Smooth endoplasmic reticulum** has no ribosomes attached to it.

The endoplasmic reticulum has a variety of functions. Because the endoplasmic reticulum forms a network throughout the cytoplasm and is attached to the other organelles, it acts as a framework to hold the organelles in place. It keeps the nonfluid structures within the cytoplasm properly positioned and distributed in relationship to each other. Secondly, the network of channels acts as a pathway for the transport of various substances from one region of a cell to another. For instance, it is responsible for the transport of proteins synthesized by ribosomes attached to it. Thirdly, it serves as a surface for chemical reactions that occur within the cell. Finally, smooth endoplasmic reticulum may be responsible for the synthesis and storage of compounds such as polysaccharides and steroids.

Most cells have very small granules (15 to 25 nm) called **ribosomes**. They are the most numerous type of organelle found in a cell. Ribosomes are composed of RNA (ribonucleic acid) and ribosomal protein. These organelles are produced in the nucleoli of the nucleus. Once they leave the nucleus they become attached to the endoplasmic reticulum or float free in the cytoplasm. Ribosomes play an important role in the manufacture of proteins. The ribosomes found in association with rough endoplasmic reticulum produce proteins for export from the cell. Free ribosomes located in the cytoplasm produce proteins for use within the cell.

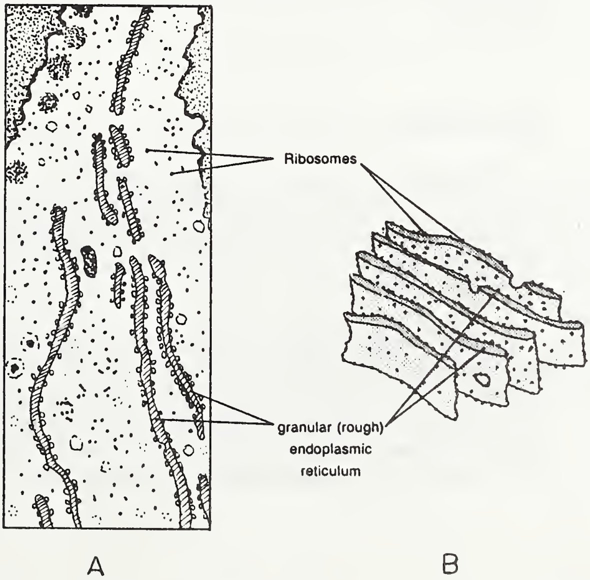


Figure 10: (A) Artist's concept of electron micrograph showing endoplasmic reticulum and ribosomes. (B) Three dimensional diagram of endoplasmic reticulum and ribosomes.

The Lysosomes

The lysosomes are a group of intracellular organelles found in animal cells. All lysosomes are believed to be formed from Golgi complexes. In the cytoplasm, the lysosome resembles a small sac or vesicle surrounded by a single membrane. Within this membrane are a variety of very powerful digestive enzymes capable of breaking down (hydrolyzing) many kinds of molecules. These enzymes are also capable of digesting any bacteria that enter the cell. From what we have said, it is not surprising that the logical function of the lysosomes is to break down food entering the cell. Scientists suggest, that in order to accomplish this, the lysosome must fuse with the food particle. While the cell is fully intact the enzymes are segregated within the lysosomes thus preventing them from digesting the contents of the cell itself. Scientists have speculated that in a healthy cell, the lysosome membrane is impermeable to enzymes hence the enzymes cannot move out into the cytoplasm. However, as soon as a cell is damaged, lysosomes release their enzymes. These enzymes then initiate the reactions that break the cell down into its chemical constituents. These materials (chemicals) may be utilized by other cells or be excreted. Lysosomes are sometimes called the ''suicide bags'' or ''suicide pockets'' of the cell.

Microfilaments

Microfilaments are long, thin, rodlike structures that range in diameter from 3 nm to 12 nm and are of varying lengths. They may occur in bundles scattered throughout the cytoplasm or as a network within the cytoplasm. They are composed of one of two proteins, either actin or mysosin. These two proteins are responsible for contraction in muscle cells. In cells other than muscle cells, microfilaments are responsible for movement of the entire cell by ameboid motion or movements within the cell by cytoplasmic streaming. When microfilaments contract, they can cause depression, infolding and other movements of the cell membrane. They are responsible for the pinching off of the cell membrane when vacuoles are formed by pinocytosis and phagocytosis. Besides those functions associated with motion, microfilaments also provide support and give shape to a cell. See Figure 4 on page 11 of this lesson.

Microtubules

Microtubules are long, straight cylindrical structures with a diameter varying between 18 and 30 nm with the average being 25 nm. They can occur free or in bundles within the cytoplasm. Their rather stiff nature provides rigidity and support in those parts of the cell where they are found. In conjunction with microfilaments they provide support and give shape to a cell.

Microtubules are suspected to serve as conducting channels for moving various substances within the cell. The microtubules also assist the microfilaments in pseudopodia formation during ameboid movement. They are found in cilia and flagella in the characteristic 9 plus 2 arrangement and play a role in the motion of these organelles. They are also part of the structure of the centrioles and the spindle that forms during cell division. More will be said of this as these particular organelles are discussed. See Figure 4 on page 11 of this lesson.

The Centrosome and Centrioles

The centrosome appears as a small round body usually located near the nucleus. It is found in all animal cells, some algae and fungi cells, but missing from all higher plants. Within the centrosome are a pair of hollow cylindrical shaped structures, the **centrioles**. Each centriole is 300 to 500 nm long, 150 nm in diameter and consists of a ring of nine evenly spaced bundles. Each bundle consists of three microtubules. The centrioles are oriented at right angles to each other. The longitudinal axis of one centriole is at right angles to the longitudinal axis of the other.

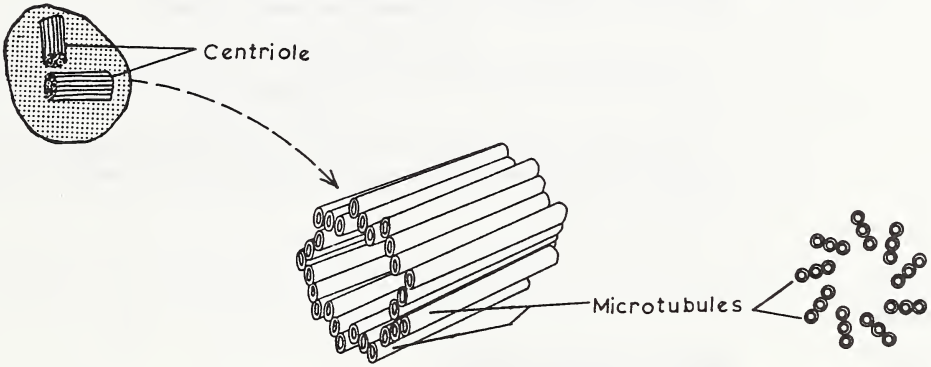


Figure 11: Structure of the centrosome and centrioles

The centriole plays an important role during cell reproduction. Just before a cell divides the two centrioles duplicate. The pairs migrate to opposite sides of the nucleus to form the poles of the spindle. At the same time spindle fibres (composed of microtubules) begin to develop between the centrioles at each pole. While this is going on, the nucleoli and nuclear membrane disappear. The chromosomes, which by this time have replicated (made exact copies of themselves), move to the center of the cell and attach themselves in a line to the spindle fibres. The replicated chromosomes then separate, moving in opposite directions to the poles. Once the chromosomes have moved to the poles the cell divides. Each cell has received a complete set of chromosomes. The role of the centrioles in this process is the organization of the spindle fibres during cell division.

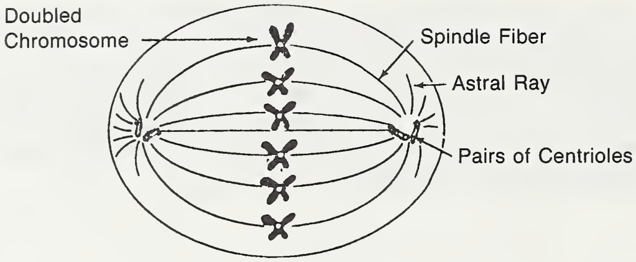


Figure 12: A group of spindle fibres form a spindle

Scientists are not entirely certain of the role that centrioles play in cell division because in plant cells the spindle still forms even though these cells lack centrioles.

Centrioles are also believed to play a role in producing the basal bodies of cilia and flagella in cells that have these structures. They may also be the bodies that direct the assembly of the microtubules.

Exercise 3

Multiple Choice Questions

______ 1. Chromatin material is usually located in the organelle called the

(a) lysosome.
(b) Golgi apparatus.
(c) pinocytic vesicle.
(d) nucleus.

______ 2. A structure that disappears during cell division and then reappears is the

(a) plasma membrane.
(b) centriole.
(c) nucleolus.
(d) cell wall.

______ 3. Structures observable only by the electron microscope include

(a) ribosomes and nucleus.
(b) ribosomes and endoplasmic reticulum.
(c) chromosomes and centrioles.
(d) nucleoli and vacuoles.

______ 4. The organelles considered to be the protein factories of a cell are the

(a) Golgi bodies.
(b) lysosomes.
(c) mitochondria.
(d) ribosomes.

______ 5. An organelle that is usually absent from plant cells is the

(a) plasma membrane.
(b) nuclear membrane.
(c) cell wall.
(d) centrosome.

______ 6. The contents of a cell can be hydrolized if enzymes escape from the

(a) endoplasmic reticulum.
(b) centrioles.
(c) lysosomes.
(d) ribosomes.

7. List three functions of the endoplasmic reticulum.

(a) ______________________________

(b) ______________________________

(c) ______________________________

8. Which organelle is responsible for protein synthesis?

____

Match the statement listed in the left-hand column with the appropriate definition or explanation presented in the right-hand column.

9. ______ Endoplasmic Reticulum
10. ______ Ribosomes
11. ______ Centrioles
12. ______ Lysosomes

(a) system of branching net-like channels extending through cytoplasm
(b) formed from Golgi complexes
(c) small bodies associated with the endoplasmic reticulum
(d) form the poles of the spindle

Circle your choice - True or False.

13. Ribosomes may be attached to the endoplasmic reticulum or suspended in the cytoplasm. T F

14. The function of the lysosomes is to break down food particles that enter the cell with the aid of its powerful enzymes. T F

15. All plant cells possess a centriole and spindle. T F

16. Centrioles are believed to play a role in the formation of cilia and flagella. T F

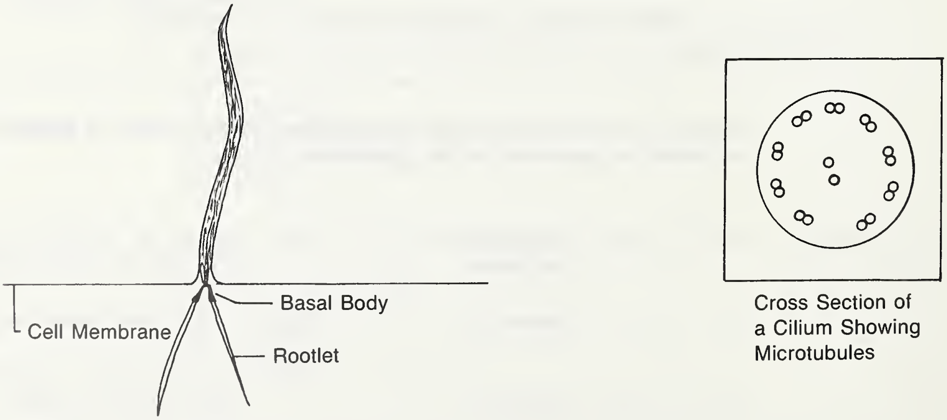
17. Microfilaments and microtubules help support the cell and give it form. T F

Please check your answers with those given on pages 31 and 32.

Cilia and Flagella

In some cells projections exist that assist the cell in propelling itself or moving substances past it. When there is only one or a few long projections from the surface of the cell, it is called a flagellum. When there are numerous short projections on the cell surface, they are known as cilia.

Both cilia and flagella contain cytoplasm bound by a cell membrane. The internal structure and origin of both types of organelles is the same. They grow out of a basal body formed by the centriole. Each cilium and flagellum consists of a ring of nine paired microtubules surrounding two central microtubules.



Cross Section of a Cilium Showing Microtubules

Figure 14: Structure of Cilium

Cilia and flagella are quite common among microorganisms and lower plants and animals. For instance, Euglena and Chlamydomonas, both photosynthetic microorganisms, use flagella to move from place to place. They will move towards light. Sponges have flagella to propel water and food particles into their bodies. The underside of the Planaria is covered with cilia which propel it along in a trail of mucus. The sperm cells of most plants and animals are flagellated. The only flagellated cell of the human body is the sperm cell. However, cilia are more common. They line the trachea (windpipe) and propel any dust particles that may be breathed in back up the windpipe into the throat for elimination.

Vacuoles

These fluid-filled spaces within the cytoplasm are surrounded by membranes that are at least similar, if not identical, to the cell membrane. The fact that many vacuoles are formed by invagination of the cell membrane would indicate this. The fluid found inside the vacuole usually contains either food or waste. Food vacuoles are formed by phagocytosis. Waste containing vacuoles release their contents through the cell membrane by exocytosis.

Plant cells often have one large vacuole that takes up much of the volume of a cell. This central vacuole may contain food, wastes and pigments. Vacuoles are also common in the cells of lower animals, such as protozoans, but are much rarer in the cells of higher animals such as birds and mammals. When present in the cells of higher animals, vacuoles are minute structures.

Generally there are two types of vacuoles: temporary and permanent.

Temporary Vacuoles:

These vacuoles form, serve a function and then disappear. Food vacuoles which contain food, pinocytic vacuoles which contain water, excretory vacuoles filled with waste products and storage vacuoles for reserve foods are examples of temporary vacuoles.

Permanent Vacuoles:

Once formed, these vacuoles remain in the cell throughout its life. The bodies of many protozoans, for example, contain contractile vacuoles. In these organisms, the contractile vacuoles regulate the water content of the cell.

The Golgi Apparatus (Golgi Complex)

In 1898, the Italian neurologist, Camillo Golgi observed in nerve cells the structure known today as the Golgi apparatus. Viewed under the light microscope, the Golgi apparatus appears as a poorly defined structure usually located near the nucleus. Under the electron microscope, the structure of these organelles becomes more obvious. They appear like a stack of disks, each disk consisting of a double membrane with a channel running through it. These structures are known as **cisternae**. At the margin of the disks the channels may become quite expanded and may pinch off from the cisternae to form **vesicles**.

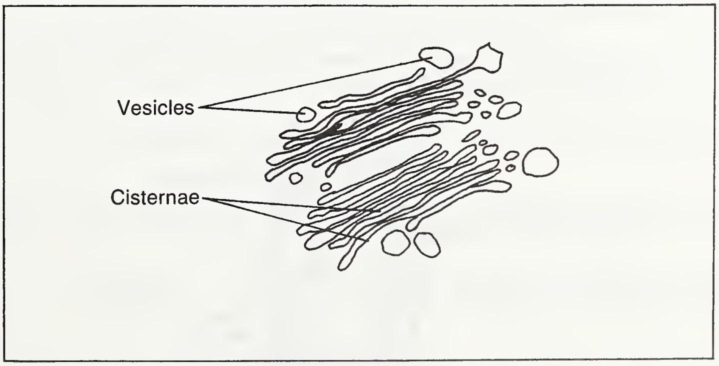


Figure 15: Cross Section of a Golgi Apparatus 78,000X
(also shown on pages 11 and 16 of this lesson)

The Golgi apparatus is found in the cells of both plants and animals. It is most conspicuous in cells that serve a secretary function, such as those of the pancreas and liver, but totally lacking in mature sperm cells and red blood cells.

The Golgi apparatus serves a variety of functions within the cell. It plays an important role in membrane construction, protein and lipid storage and particle transport across the cell membrane.

Proteins produced by the ribosomes of rough endoplasmic reticulum are transported through the endoplasmic reticulum to the Golgi apparatus. When enough proteins have accumulated in the cisternae they expand at their margins to form vesicles. The vesicles then pinch off and move to the cell membrane to secrete the proteins by a process called **exocytosis**. The membrane of the vesicle becomes a part of the cell membrane and the contents are released into the extracellular (outside the cell) fluid during this process.

The Golgi apparatus also produces vesicles filled with powerful digestive enzymes. These vesicles remain within the cell and become the lysosomes. Should a cell die or be injured the lysosomes release their enzymes which will digest most of the cell contents to their chemical constituents. These will either be reused by the body or excreted in multicellular organisms.

The Golgi apparatus is active in lipid secretion in much the same way as for protein secretion except that the lipids are manufactured in the smooth endoplasmic reticulum. The final function performed by the Golgi apparatus is the manufacture and secretion of substances known as **glycoproteins**. The Golgi apparatus manufactures carbohydrates and then combines them with proteins produced by the ribosomes. These glycoproteins are transported in the vesicles, where they are stored, to the cell membrane to be secreted into the extracellular fluid.

Plastids

Plastids are small round, oval or disc shaped organelles. They are found only in plant cells and the cells of photosynthetic microorganisms. Plastids may be colorless or they take on the color of the pigments they contain. The color of leaves, flowers, and fruits (plant organs) are due to the green, orange, yellow, or red pigments found in the plastids of the cells making up these organs. Colorless plastids are usually found in plant parts that are not exposed to light. They are associated with the storage of starches, proteins and oils.

The most important plastid in green plants is the chloroplast, which contains the green pigment chlorophyll. Chlorophyll is able to trap the energy of sunlight and use it to make food from carbon dioxide and water. This is the process known as photosynthesis.

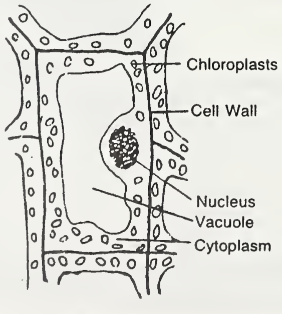


Figure 16: Plant Cell Depicting Chloroplasts

A Review of Cell Structures and Their Functions

Cell Region	Structure	Main Functions
Nucleus	Chromosomes	Carry the genes; ultimately control all cell activities.
	Nucleolus	Manufacture and storage of RNA, takes part in ribosome production.
	Nuclear membrane	Controls movement of substances in and out of the nucleus.
	Nucleoplasm	The substance in which chemical reactions within the nucleus occurs.
Cytoplasm	Endoplasmic reticulum	Connects and supports different cell parts; transports substances within the cell; provides attachment surfaces for different chemical reactions; storage of different substances; in conjunction with Golgi apparatus manufactures and packages substances for secretion.
	Golgi apparatus	Packages and transports a variety of substances (lipids, proteins, glycoproteins) to the cells surface (secretion); manufactures carbohydrates and glycoproteins.
	Ribosomes	Manufacture of proteins used within the cell and for secretion.
	Mitochondria	Manufacture of ATP (energy) from food through respiration.
	Lysosomes	Stores hydrolytic enzymes, digests food and foreign substances.
	Microfilaments	Gives support and shape to a cell; assists in movement of the cell and its contents, contraction in muscle cells.
	Microtubules	Gives support and shape to a cell; conducts substances within the cell; assists in movement of the cell; are components within the structure of centrioles, cilia, flagella and the spindle.
	Centrioles (centrosomes)	Organize spindle fibres into a spindle during cell reproduction. Produce basal bodies of flagella and cilia.
	Chloroplasts	Produce food by photosynthesis.
	Other plastids	Store pigments or accumulate starch, protein or oil.
	Vacuoles	Transport, storage and processing of a variety of substances such as food, water and other materials.
Surface	Cell membrane	Protects contents of cell; controls exit and entrance of substances to cell.
	Cell wall	Freely permeable to all substances; supports and protects plant cells; not present in animal cells.
	Cilia and flagella	Movement of the entire cell (locomotion), movement of substances along or past a cell in order to capture food.

Exercise 4

1. Which scientist is credited with the discovery of the Golgi apparatus?

   ____

2. List two types of cells that are completely devoid of the Golgi complex.

   (a) ______________________________

   (b) ______________________________

3. Where are glycoproteins manufactured?

   ____

   ____

4. Vacuoles are most commonly found in what type of cell?

   ____

5. List the two general types of vacuoles.

   (a) ______________________________

   (b) ______________________________

6. Of what value would flagella be to photosynthetic microorganisms.

   ____

   ____

7. List two structures associated exclusively with plant cells.

   (a) ______________________________

   (b) ______________________________

Please check your answers with those given on page 32.

ANSWERS TO SELF-CORRECTING EXERCISES

Exercise 1, page 9

1. **True**
2. **True**
3. **False** - According to spontaneous generation living things originate from nonliving matter.
4. **False** - Robert Hooke only saw the empty cell walls of cells.
5. **True**
6. **True**
7. **True**
8. **False** - Cell fragments can be separated from each other using a centrifuge.
9. **True**
10. **d**
11. **d**
12. **c**
13. **c**
14. **d**
15. **a**

Exercise 2, page 19

1. **A**
2. **B**
3. **C**
4. **G**
5. **D**
6. **F**
7. **E**
8. **Any of: Endoplasmic reticulum, Ribosomes, Mitochondria, Golgi apparatus, Lysosomes, Pinocytic vesicles, Nucleus, Vacuoles, Microtubules, Microfilaments, Centrioles**
9. Any of: **Nucleoplasm, Nucleoli, Chromatin, Chromosomes**
10. **It is responsible for synthesis of RNA and proteins.**
11. **They are folds in the inner membrane of a mitochondrion.**
12. **True**
13. **True**
14. **True**
15. **False -** Mitochondria are the 'powerhouses' of a cell.
16. **a**
17. **c**
18. **b**
19. **a**

Exercise 3, page 24

1. **d**
2. **c**
3. **b**
4. **d**
5. **d**
6. **c**
7. (a) **Storage system for various substances.**
   (b) **Stabilizes various organelles.**
   (c) **Serves as a surface area for chemical reactions.**
   (d) **Transports various substances within the cell.**
   (e) **Synthesis and storage of polysaccharides and steroids.**

8. **The ribosomes.**
9. **A**
10. **C**
11. **D**
12. **B**
13. **True**
14. **True**
15. **False -** Most plant cells lack a centriole.
16. **True**
17. **True**

Exercise 4, page 30

1. **Camillo Golgi**, an Italian neurologist, discovered this organelle.

2. **Mature red blood cells** and **sperm cells** lack the Golgi complex.

3. They are manufactured in the **Golgi complex**.

4. They are found in the cell of **plants and lower animals**.

5. There are **temporary** and **permanent** vacuoles.

6. Flagella enable them to **move towards the light**.

7. The **cell wall** and **plastids** are only found in plants.

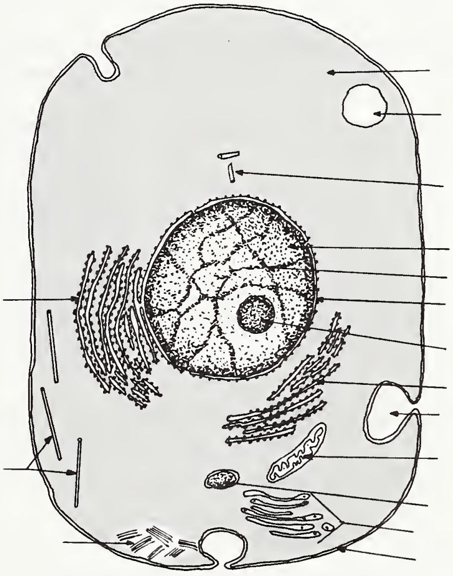
EXERCISES TO BE SENT IN FOR CORRECTION

1. Label the generalized animal cell indicating the following:

Mitochondrion
Nucleoplasm
Vacuole
Cytoplasm
Cell membrane

Endoplasmic reticulum
Centrosome
Nuclear membrane
Chromatin
Nucleolus

Pinocytic vesicle
Ribosome
Microtubules
Microfilaments
Golgi apparatus
Lysosome



2. Identify the structure or substances described in the right-hand column by filling in the blank on the left-hand side.

________________________ A. Controls and determines what materials may enter or leave the cell.

________________________ B. Comprises all the material located between the nucleus and the plasma membrane.

________________________ C. May be found attached to the endoplasmic reticulum as well as suspended in the cytoplasm.

________________________ D. Chemical analysis shows water 80%, protein 15%, fat or lipid 3%, carbohydrate 1%, inorganic substances 1%.

____________________ E. A large organelle that provides control over cell structure and directs the metabolic activities of the cell.

____________________ F. Serves to protect the contents of the nucleus as well as control what enters or leaves the nucleus.

____________________ G. Threadlike structures containing the genes, located in the nucleoplasm.

____________________ H. Numerous hair-like structures that move substances over the outer surface of a cell.

____________________ I. The sausage or rod shaped organelle known as the power house of the cell.

____________________ J. Folding of the inner membrane of mitochondria.

____________________ K. Present in the cytoplasm as colloids hence possess electrical charges that repel each other.

____________________ L. Form the basal bodies of a flagellum.

____________________ M. An organelle produced by the Golgi complex.

3. Describe the structure of the cell membrane as revealed by the electron microscope.

____

____

____

____

____

____

4. Numerous chemical activities occur simultaneously in the cytoplasm of a cell. Why is there no interference of one reaction with another?

____

____

____

____

5. What differences, if any, exist between chromatin and chromosomes.

____

____

____

____

____

____

6. Which of the following would you consider to be temporary vacuoles? Place an "X" in the appropriate blank(s).

(a) food vacuoles ________
(b) excretory vacuoles ________
(c) storage vacuoles ________
(d) pinocytic vacuoles ________
(e) contractile vacuoles ________

7. If you were to grind up a bunch of liver cells from a rat and put the contents of the cells in water, in which order if any would salts, proteins, ribosomes and mitochondria settle out of solution?

____

____

____

____

____

____

8. List 4 organelles in a generalized animal cell that are bounded by unit membranes.

____

____

______ 9. The cell walls of plants are constructed of

(a) a polysaccharide.
(b) protein.
(c) lipid.
(d) inorganic substances.

10. List four structures controlling external and internal movements of substances within a cell.

____

____

______ 11. The human ovum is approximately 0.09 mm in diameter. Expressed in micrometres this diameter would be

(a) 0.000 009 μm.
(b) 9 μm.
(c) 0.009 μm.
(d) 90 μm.

______ 12. Energy is released within the cell by the process of

(a) diffusion.
(b) respiration.
(c) metabolism.
(d) phagocytosis.

______ 13. If the volumes of four cells were equal but they all had different shapes, the cell capable of the highest rate of metabolism would be

(a) spherical.
(b) polyhedral.
(c) egg-shaped.
(d) needle-shaped.

Circle your choice. True or False.

14. All the cells in a pig have the same number of nucleoli. T F

15. Vacuoles in cells have a membrane similar to the cell membrane. T F

16. Ribosomes are often referred to as "suicide bags" or "suicide pockets" of the cells. T F

17. All plant cells possess a centriole and spindle. T F

18. Scientific studies have shown that numerous activities essential to life occur at the cellular level of living organisms. T F

19. The development of the microscope contributed significantly to our knowledge in biology. T F

20. The English inventor, Robert Hooke, using his crude microscope, reported having observed compartments in cork. T F

21. Anton von Leeuwenhoek's observations helped to promote the doctrine of spontaneous generation. T F

22. All cells possess essentially the same size, shape, colour and structures. T F

23. The light and electron microscopes possess the same magnifying and resolving power. T F

24. The micrometre is a suitable unit of microscopic measurement used in biology. T F

Please submit pages 33 to 37.

END OF LESSON 1

QUESTIONNAIRE FOR SCIENCE COURSES

PLEASE COMPLETE THIS FORM AND RETURN IT WITH YOUR FIRST LESSON.

Course: ______________________________

Name: ______________________________ File No.: ______________

Address: ______________________________ Birth Date: ______________

______________________________ Postal Code: ______________

Phone Number: ______________________

1. What were your gradings in the following subjects (if taken)?

   Math. Gr. IX ______
   Mathematics 10 ______
   Mathematics 20 ______
   Mathematics 30 ______
   Science Gr. IX ______
   Biology 10 ______
   Biology 20 ______
   Biology 30 ______
   Chemistry 10 ______
   Chemistry 20 ______
   Chemistry 30 ______
   Physics 10 ______
   Physics 20 ______
   Physics 30 ______
   Physics 22 ______
   Physics 32 ______

2. If you are repeating this course, what was your previous mark? ______________________

3. List any special qualifications or handicaps (jobs, illness, disabilities, etc.) which may influence your progress in this course.

   ____

4. List any other subjects you are studying by correspondence instruction.

   ____

5. Why are you taking this course? (For matriculation, for diploma, for general interest, etc.) Explain.

   ____

6. What school are you attending, if any? ______________________

7. If you took this course previously, where did you carry out the laboratory work? Explain.

   ____

   ____

8. What laboratory arrangement have you made for this year?

   ____

   ____

9. Do you plan to purchase a laboratory kit? ______________________

10. Will you have the use of a microscope (for biology students)? ______________________

Sci. Gen. - 3 - 85

Name: ____ File No.: ______________________

1					A			
2					B			
3					C			
4					D			
5					E			
6					F			
7					G			
8					H			
9					I			
10					J			
11								
12								
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15								
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17								
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20								
Exam.								

LESSON RECORD FORM

3230 Biology 30
Revised 03/89

FOR STUDENT USE ONLY

Date Lesson Submitted ______

Time Spent on Lesson ______

(If label is missing
or incorrect)

File Number ______

Lesson Number ______

FOR SCHOOL USE ONLY

Assigned Teacher: ______

Lesson Grading: ______

Additional Grading E/R/P Code: ______

Mark: ______

Graded by: ______

Assignment Code: ______

Date Lesson Received: ______

Lesson Recorded ______

Student's Questions and Comments

Apply Lesson Label Here

Name ______

Address ______

Postal Code ______

Please verify that preprinted label is for correct course and lesson.

Teacher's Comments:

______
Correspondence Teacher

St. Serv. 1-86

ALBERTA CORRESPONDENCE SCHOOL

MAILING INSTRUCTIONS FOR CORRESPONDENCE LESSONS

1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

First Class

Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

OBJECTIVES

By the end of Lesson 2 the student should be able to:

1. **Write** the definition of homeostasis.
2. **Classify** any given mixture as either a solution, suspension or colloid by examining its physical properties.
3. **Define** diffusion and osmosis and **explain** these processes.
4. **Explain** the effects of temperature, molecular size and concentration gradient on the rate of diffusion.
5. **Give examples** of diffusion and osmosis in the human body.
6. **Explain** the characteristics of a semipermeable membrane.
7. **Differentiate** between an isotonic, hypertonic and hypotonic solution.
8. **Explain** the causes of plasmolysis and cytolysis in red blood cells.
9. **Write** a definition for the term dialysis.
10. **Distinguish** between active and passive transport.
11. **Explain** the importance of energy and carrier molecules in active transport.
12. **Differentiate** between pinocytosis and phagocytosis.
13. **Differentiate** between endocytosis and exocytosis.
14. **Give** examples of internal and external stress.
15. **Explain** the differences between a negative and a positive feedback system.
16. **Construct** a simple negative feedback system consisting of a receptor, control centre, effector, stimulus and feedback.
17. **Describe** the two methods used to transmit messages between the components of a feedback system.
18. **Distinguish** between an acid and a base in terms of the hydrogen ion and hydroxyl ion concentrations.
19. **Identify** a neutralization reaction by examining the reactants (an acid and a base) and the products (a salt and water).
20. **Explain** the basis of the pH scale.

21. **Determine** whether a substance is acidic, basic or neutral when given the pH.
22. **Define** and **explain** the function of a buffer system.
23. **Explain** briefly how buffers can control the pH of the body.
24. Briefly **describe** the structure of an enzyme.
25. **Recognize** an enzyme by its ''ase'' suffix.
26. **Explain** how enzymes speed up reactions occurring at normal body temperatures.
27. **Explain** the ''lock-and-key'' theory of enzymes.
28. **Identify** the ''active site'' of an enzyme.
29. **Describe** the effects of temperature, pH and competitive inhibitors on enzyme activity.
30. **Explain** why a competitive inhibitor interferes with enzyme action.

PHYSICAL PROPERTIES OF CELLS

Introduction

This course began with an examination of ''the building blocks of life'', the cells. This background provides the information necessary for a discussion of cellular processes. Processes that will be discussed are diffusion, osmosis, active transport, endocytosis and exocytosis.

In order for the various cellular processes to function properly the external environment of each cell must be kept constant. In humans, the external environment surrounding each cell is actually a derivative of blood plasma, providing the watery environment necessary for the exchange of nutrients, wastes and dissolved gases. Because this fluid is outside the cells, we refer to it as **extracellular fluid**.

The composition of the extracellular fluid must remain constant to facilitate the removal of metabolic wastes (such as CO_2) and the provision of a constant supply of oxygen and nutrients. The maintenance of this stable or constant environment condusive to cellular activity is called **homeostasis**. A large number of homeostatic mechanisms maintain this stable or constant environment through a wide variety of adjustments and controls. This lesson will also examine specific examples of homeostatic mechanisms which regulate the body and its systems.

Exchange of Materials

READ

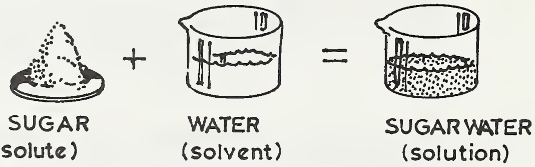
Read the sections of your text which deal with ''Cell Processes'' (pp. 25 to 30).

The continued survival of multicellular organisms, such as humans, depends upon a constant exchange of materials. Food, oxygen and other essential substances that are taken into the body from the environment must eventually be transported throughout the body to permit absorption by all cells. The body must also remove accumulated metabolic wastes and other materials from the extracellular fluid surrounding the cells to eventually be passed out into the environment. Nutrients and wastes are transported to and from the cells by the circulatory and lymphatic systems. These systems will be dealt with in Lessons 9 and 10. Our major concern in this lesson is to review the mechanisms by which materials pass into and out of the cells.

A. Solutions, Suspensions and Colloids

All substances passing through the cell membrane must be in solution. A **solution** is a mixture of two or more substances, one substance dissolved in the other. The dissolved substances are called the **solutes** and the substance in which the solutes are dissolved is called the **solvent**.

When sugar is dissolved in water a solution is formed. In this case, water is the dissolving substance (solvent) and sugar is the dissolved substance (solute). A solution is formed when the molecules or ions of the solute are spread throughout the molecules of the solvent.



As a solution is formed, the molecules or ions of the solute spread throughout the solvent to become evenly distributed in the solvent. This means that, in the above diagram, the solution of sugar water would have just as many sugar molecules at the top as at the bottom of the beaker. The same would be true if you were to sample the solution at a later date. The solute does not settle out of solution.

Water is the universal solvent for all living things. It is the most abundant substance present in life on earth, making up between 65 and 95 per cent of the body weight of all living things. In the human body, water is found to make up 60% of the red blood cells, 75% of muscle tissue and 92% of the blood plasma.

Those substances (solutes) which are required for the growth and maintenance of the cells are broken down in the digestive tract by a variety of digestive enzymes. Next, they become dissolved in water (the solvent) and absorbed by the cells lining the walls of the small intestine. Once absorbed, the substances in solution are distributed throughout the body via the lymphatic and circulatory systems.

Substances which do not dissolve in water cannot be absorbed or distributed throughout the human body. Cellulose, the substance which makes up the walls of plant cells, is taken into the human digestive tract whenever vegetables or whole cereal grains are eaten. Particles of cellulose mix with water but do not dissolve, forming a mixture known as a **suspension**. A suspension differs from a solution in that the particles in suspension will eventually settle out.

It is the size of the particles which determine whether a suspension or a solution will be formed. Particles such as cellulose, flour and corn starch, which are large enough to be seen with a light microscope, settle out because the force of gravity is stronger than the force that holds them in suspension.

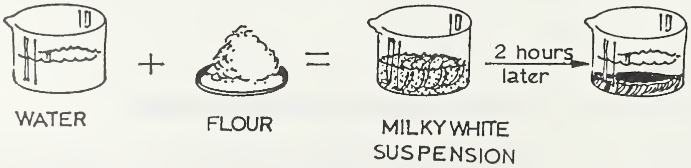


Figure 1: Mixing flour and water creates a milky white suspension. After a period of time, however, the water is clear again since the particles of flour have settled to the bottom of the beaker.

Most of the nutrients which enter the human digestive tract are large molecules which become suspended in digestive juices. Enzymes within these juices break down the large molecules until they are small enough to dissolve in water and thus be absorbed and transported to the cells. Most proteins, fats, sugars and starches are broken down to a smaller, more usable, size. Cellulose, however, is unaffected by the enzymes produced within the human digestive tract. This means that molecules of cellulose will simply pass through the digestive tract unchanged.

Protoplasm and most other fluids in living organisms are neither solutions nor suspensions. Living cells contain mixtures classified as **colloids**. A colloidal suspension results when particles ranging from 0.000001 mm to 0.0002 mm are mixed with a fluid, usually water. Particles within this size range are too large to dissolve in the fluid but too small to settle out. Colloid particles are larger than most chemical molecules but cannot be seen with a light microscope.

The name for this type of mixture is derived from the Greek word **kollos** - meaning glue. It is not surprising then, to learn that glue is a colloid of animal gelatin and water. Other familiar products which are colloids or were colloidal during their manufacture include ceramics, cosmetics, detergents, soaps, paints, paper, pesticides and plastics.

The relationship between the suspended particles and the liquid in which they are suspended can change from time to time. When gelatin is mixed with warm water the molecules of this simple protein are folded and contracted, becoming widely scattered among the water molecules. In this state the colloid is called a **sol**. As the mixture cools, the gelatin molecules straighten out and expand to form a firm network that traps the water molecules. In this state the colloid forms a **gel**.

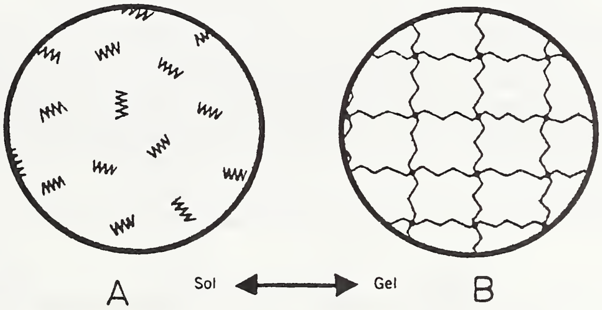


Figure 2: A. The colloidal particles are shrunken and folded, allowing for free movement of the water molecules. B. The particles have expanded, forming a network which traps the water molecules. As the arrows indicate, the sol state can be changed into the gel state and vice versa.

The cytoplasm within the cells of living organisms can be in either a sol or gel state or it can vary in different parts of the cell. In the "sol" state the cellular organelles are spaced far apart in the fluid, while in the "gel" state, the organelles are closer together in a jelly-like cytoplasm.

The ability of cytoplasm to alternate between the "sol" and "gel" states makes it possible for cells, such as the white blood cells, to engulf bacteria and other particles. The cytoplasm of the white blood cell flows out and around the particle being engulfed. This process is known as **phagocytosis** and will be dealt with in more detail later on in this lesson.

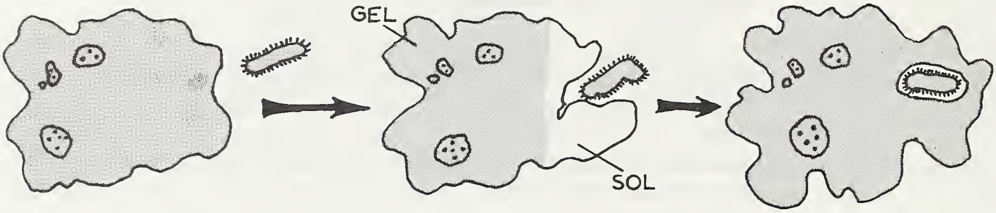


Figure 3: In order for phagocytosis to occur the cytoplasm must become liquid, flowing out and around the particle being engulfed. Notice that only a portion of the cytoplasm is in the "sol" state, the remainder is still a "gel."

B. Diffusion

So far, this lesson has dealt with the various types of mixtures — solutions, suspensions and colloids. We will now concentrate on those processes which provide for the exchange of materials between the cell and its environment.

Many substances can enter a cell by a simple process known as **diffusion**. Diffusion is a passive process by which molecules or ions move from an area of high concentration to an area of low concentration (See Figure 4). Diffusion is considered to be passive since no external source of energy is required for the process to take place.

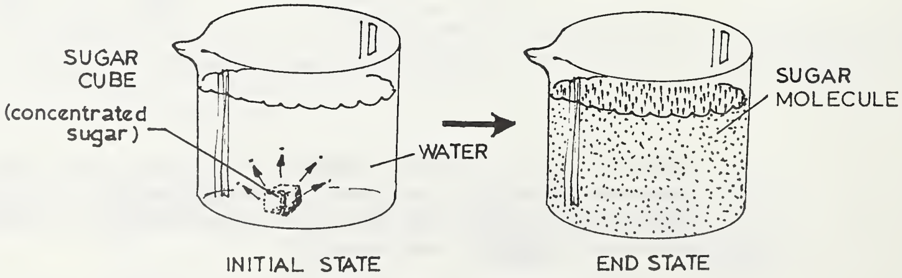


Figure 4: Diffusion. In the initial state sugar molecules are concentrated in the sugar cube and thus distributed unevenly. A given sugar molecule will have more freedom to move in the direction of lower concentrations. This eventually leads to the end state — an even distribution of sugar molecules within the solution.

What force accounts for the movement of these molecules? It is believed that all molecules are constantly moving, due to the movement of their electrons. The electrons racing around the nucleus of each atom create an internal kinetic energy, resulting in movement. The molecules move in straight lines until they collide with another molecule and change directions.

Movement caused by the actions of molecules can be seen under an ordinary light microscope. If you were to examine small organisms, such as bacteria in a water suspension, you would see that the bacteria move with a jiggling motion. This movement is caused by the constant bombarding of the bacteria by water molecules. Even dead bacteria or droplets of ink demonstrate this type of movement, known as **Brownian movement**. The English botanist, Robert Brown, was the first to describe this phenomenon in 1827.

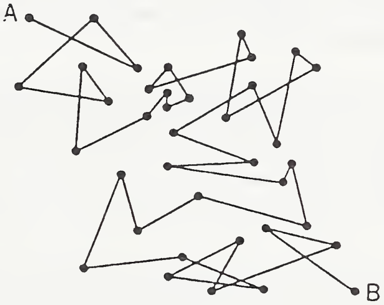


Figure 5: The paths taken by a particle moving from point A to point B by Brownian movement.

As moving molecules collide they tend to change direction and spread out from an area of high concentration to an area of lower concentration. e.g. When a bottle of perfume is opened in one corner of a sealed room, the odor gradually spreads to every part of the room, even though there are no air currents present. This occurs because the liquid perfume evaporated and the perfume molecules collided with the other air molecules, spreading by Brownian movement throughout the room. This process of diffusion continues until the perfume molecules are uniformly distributed throughout the room. This does not mean that all movement stops, just that the net movement of molecules from one area to another ceases to take place.

The **rate of diffusion** is influenced by several factors. Some of these include:

1. temperature.
2. size of the molecules.
3. concentration gradient.

For more information on these factors, please refer to page 26 of the text.

Diffusion plays an important role in living cells, for it often happens that particles inside a cell are distributed unevenly. Diffusion will then tend to equalize the distribution. This is one way in which materials are transported from place to place in cells. Diffusion also facilitates transport of some materials across cell membranes. For example, carbon dioxide accumulates in cells as a by-product of cellular respiration and readily diffuses from the inside of cells to the outside because concentrations are higher inside the cell than out. Water and oxygen also diffuse readily across cell membranes, as do some minerals and food molecules.

C. Osmosis

The cell membrane has the unique ability to select which substances may pass through it. When a membrane is capable of selecting the molecules which may pass through it, it is said to be **selectively permeable** or **semipermeable**. The size of the cell pores help to determine this.

All nutrients entering the cell and all waste products leaving the cell must be soluble in water. **Osmosis is the diffusion of water through a selectively permeable membrane**, from a region of higher concentration of water molecules to a region of lesser concentration of water molecules. Notice that osmosis refers only to the diffusion of **water**. This means that the concentrations mentioned refer only to the **concentration of water molecules**.

When two solutions are separated by a semipermeable membrane, an **osmotic system** is set up. Living cells exist in an osmotic system. The cell membrane separates the cytoplasm within the cell from the extracellular fluid surrounding the cell.

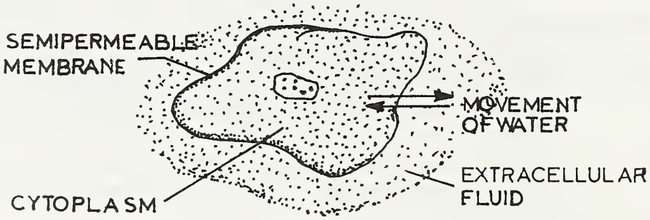


Figure 6: The osmotic system of living cells.

An experiment to demonstrate osmosis, and the resulting force known as **osmotic pressure**, is shown in Figure 7. A solution consisting of sugar and water is placed in a glass apparatus known as a thistle tube and the large opening is covered by a semipermeable membrane. This membrane permits small water molecules to pass through but it prevents the passage of sugar.

What force accounts for the movement of these molecules? It is believed that all molecules are constantly moving, due to the movement of their electrons. The electrons racing around the nucleus of each atom create an internal kinetic energy, resulting in movement. The molecules move in straight lines until they collide with another molecule and change directions.

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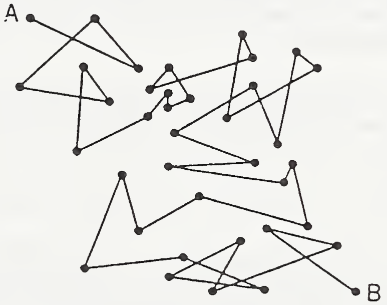

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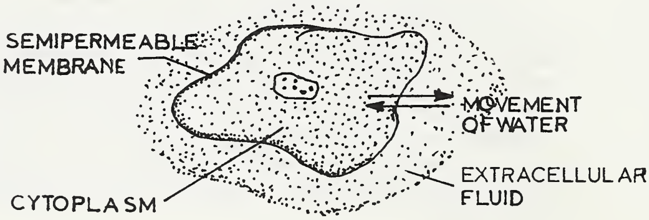

Figure 6: The osmotic system of living cells.

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The movement of water will continue in an osmotic system until the concentration on both sides of the membrane equalizes, or, until the pressure created by the water on the hypertonic side of the membrane eventually stops further entry of water. This osmotic pressure is also known as **turgor pressure** . Turgor is the pressure that is built up inside a cell as water diffuses into it by means of osmosis. Turgor pressure is useful in the soft tissues of plants (leaves, petals and soft stems); keeping them stiff and firm. Animal cells do not possess cell walls like plant cells. Thus, in animal cells, turgor pressure cannot build up to a point at which osmosis ceases. Pure water would continue to diffuse into an animal cell until its bursts. For this reason, the extracellular fluid surrounding human cells is basically isotonic with the cytoplasm of the cells.

Remember that the cell has no control over osmosis. The direction in which water diffuses depends only on the different concentrations of water molecules inside and outside the cell. Red blood cells are normally found in an isotonic solution — the blood plasma. While in the blood plasma, water enters and leaves the cell at a constant rate. If the rate of diffusion is the same in both directions, then the cell does not gain or lose water.

Red blood cells which are placed in fresh water (a hypotonic solution) quickly swell and burst, due to the rapid movement of water molecules into the cell. This bursting of the cell is called **cytolysis**.

Your text, (p. 28) has incorrectly referred to the bursting of cells as **plasmolysis**. This is incorrect! Plasmolysis actually refers to the shrinkage of cytoplasm away from the walls of a plant cell. Plant cells placed in a hypertonic solution lose water due to osmosis. As water leaves the plant cell, the volume of the cytoplasm decreases and it shrinks away from the rigid cell walls. Red blood cells placed in a hypertonic solution also lose water due to osmosis. Water leaving the red blood cell causes it to shrink and become wrinkled or **crenated**.

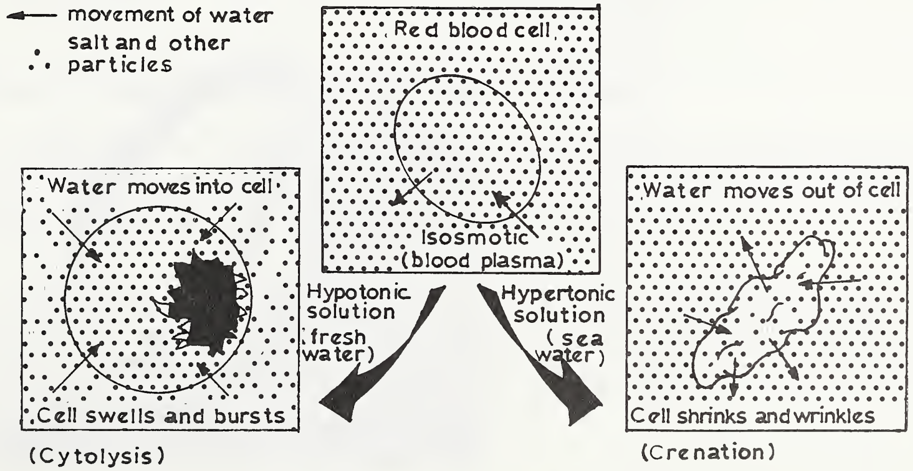


Figure 10: The swelling or shrinkage of a red blood cell is determined by the concentration of solutes in the cell and in the surrounding medium. Red blood cells burst when placed in a hypotonic solution and shrink in a hypertonic solution.

Dialysis is the process which involves the movement of some solute molecules through the membrane but not others. This is the basis of the artificial kidney (See Lesson 14).

D. Active Transport

Review the section of your text which deals with "active transport" (pp. 28 and 29).

The movement of molecules and ions across the cell membrane by diffusion and osmosis occurs without any energy being expended by the cell. We refer to this movement of molecules or ions from a region of higher concentration to a region of lower concentration as **passive transport**. One could think of passive transport as being similar to a ball rolling down a hill (See Figure 11).

The difference in concentration of molecules on each side of the membrane is the **concentration gradient**. This gradient may be thought of as the slope of a hill. A ball will roll down a hill without the input of extra energy but energy is needed when going against the concentration gradient, that is, when rolling the ball up the hill.

The process by which molecules and ions are transported across the plasma membrane, against the concentration gradient, i.e. from an area of low concentration to an area of high concentration, is called **active transport**. Energy, in the form of ATP, and some enzymes are used to move essential molecules across the membrane. In fact, a typical body cell probably expends up to 40 percent of its ATP for active transport. The ATP necessary for active transport are supplied by the mitochondria ("the powerhouses of the cell"). It is not surprising then, to find large numbers of mitochondria in cells which must carry out a lot of active transport.

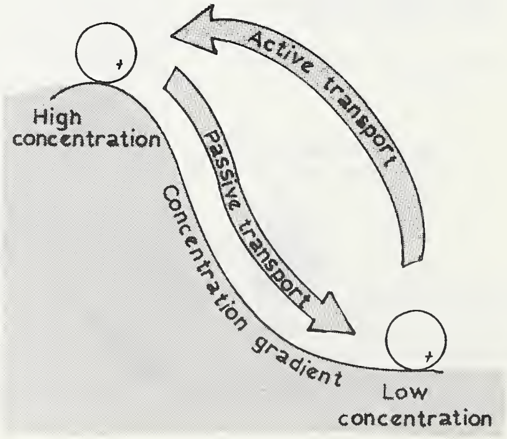


Figure 11: Active and passive transport. No added energy is necessary to roll a ball down a hill. Moving the ball up the hill, against the gradient, does require the input of energy (ATP).

E. Endocytosis — Pinocytosis and Phagocytosis

Many small particles, such as dissolved solids, ions, gases and water molecules, enter cells by diffusion through cell membranes. Other materials, though, are too large to enter the cell in this way. Larger molecules, such as amino acids, salts and certain proteins, enter cells by an energy-dependent process known as **pinocytosis**. Many cells are able to form invaginations (infoldings) of the cell membrane known as **pinocytic vesicles**. Fluid surrounding the cell enters the pinocytic vesicles, which then pinch off from the cell membrane. The resulting vacuoles inside of the cell contain water soluble substances which in time, are released and become mixed with the cytoplasm (See Figure 12).

Pinocytosis, which in Greek means ''cell drinking,'' is a process which allows the cell to take in essential, soluble molecules that ordinarily would not be able to penetrate the cell membrane. Cells of the kidney and urinary bladder are just two examples of cells which actively carry out pinocytosis.

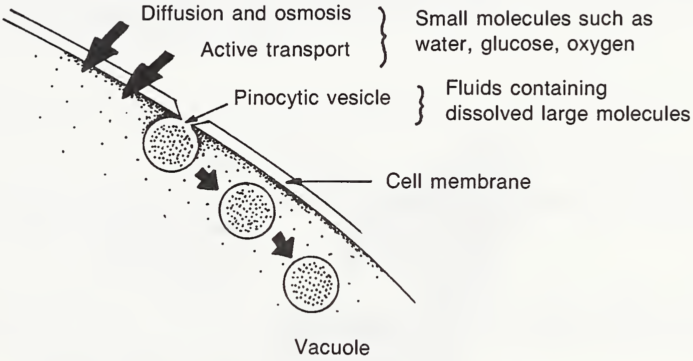

Diffusion and osmosis
Active transport
Small molecules such as water, glucose, oxygen
Pinocytic vesicle
Fluids containing dissolved large molecules
Cell membrane
Vacuole

Figure 12: Methods of transport across the cell membrane.

Phagocytosis, or ''cell eating'' is another active process, like pinocytosis by which cells take in substances across the plasma membrane. Large particles are engulfed and brought into the cell by phagocytosis. White blood cells use phagocytosis to engulf and neutralize foreign materials such as bacteria, cell debris or even damaged cells.

Phagocytosis occurs when projections of the cytoplasm, called **pseudopodia**, surround and engulf solid particles outside of the cell. Once a particle is surrounded, the cell membrane folds inwardly, forming a membranous sac around the particle. This newly formed sac is called a **phagocytic vacuole**. The vacuole breaks away from the outer membrane and cytoplasmic enzymes enter the vacuole to digest the particle within.

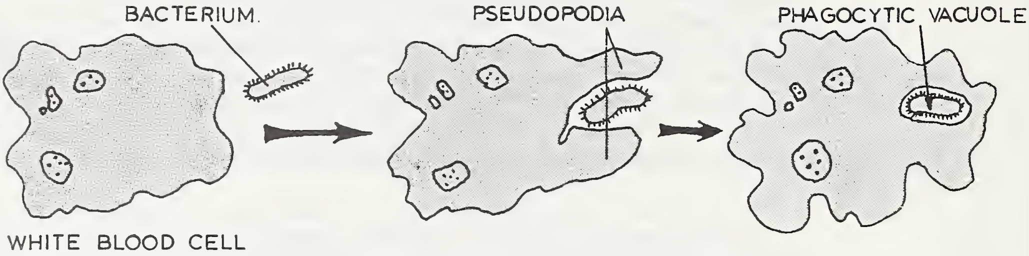


Figure 13: A white blood cell engulfing a bacterium using the process of phagocytosis.

The movement of materials into the cell by either phagocytosis or pinocytosis is referred to as **endocytosis**. The reverse process, by which materials within the cell are excreted or secreted, is referred to as **exocytosis**.

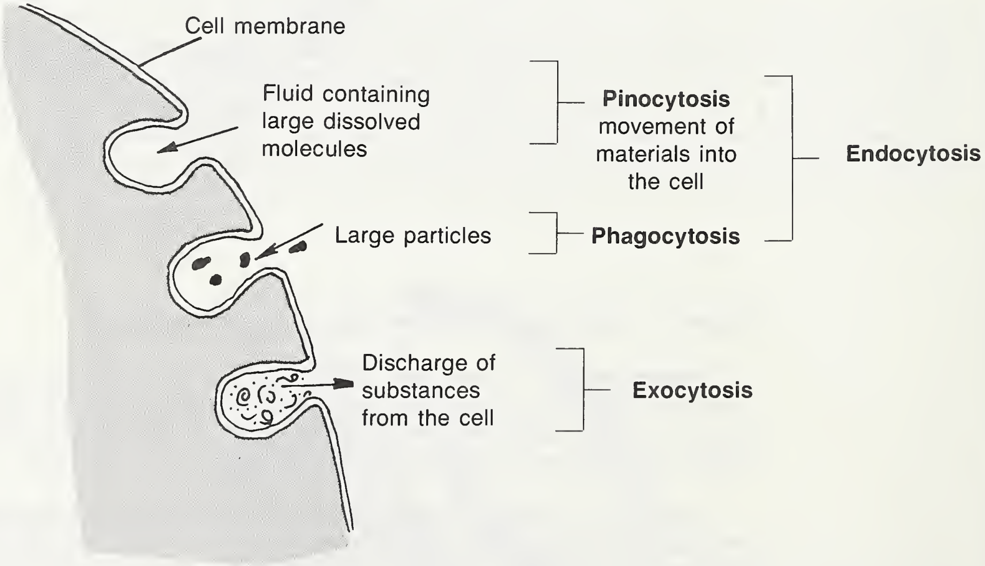

Cell membrane
Fluid containing large dissolved molecules
Pinocytosis movement of materials into the cell
Large particles
Phagocytosis
Endocytosis
Discharge of substances from the cell
Exocytosis

Figure 14: A summary of the methods by which large molecules enter and leave a cell.

F. Exocytosis

The discharge of substances from the cell into the extracellular fluid is called **exocytosis**. Exocytosis is another active process since energy is required for this process to take place. Materials which are to be excreted or secreted by the cell are contained within membranous sacs. Exocytosis occurs when the membranous sac or vacuole moves to the surface of the cell and its membrane fuses with the cell membrane. The sac then opens to the outside, discharging its contents.

Some of the materials which must pass through the plasma membrane by exocytosis include indigestible wastes, large proteins and fat droplets.

Exercise 1

Circle the word which will best complete the following statements.

1. The movement of ammonia molecules from a bottle to the far corner of a room would be an example of (diffusion/dialysis/osmosis).

2. The smaller the molecule, the (faster/slower) its movement.

3. A membrane which would **not** allow any molecules to pass through would be (impermeable/semipermeable/permeable).

4. If water passes back and forth through a cell membrane, the solution outside the membrane is probably (hypotonic/hypertonic/isotonic) to the solution within the membrane.

5. A membrane which allows sugar molecules to pass through, but not protein molecules, would be a demonstration of (diffusion/osmosis/dialysis).

6. A cell contains 10 micromoles of sodium ions in the cytoplasm and 8 micromoles of sodium ions in the extracellular fluid. Sodium ions continue to enter the cell by the process of (osmosis/dialysis/active transport/passive transport).

7. Active transport differs from passive transport because it requires (a concentration gradient/a movement of molecules/energy).

8. Match the statements in column I with the item given in column II on the right. Write the letter of the item described in the blank beside each statement. **Do not** use any letter more than once.

	Column I	**Column II**
______	the watery environment surrounding each cell	A. suspension
______	type of mixture in which the solutes are dissolved in a solvent	B. cytoplasm
		C. colloid
______	the universal solvent of all living things	D. extracellular fluid
______	type of mixture in which the particles settle out	E. solution
______	transports nutrients and wastes to and from the cells	F. osmosis
______	term derived from the Greek word meaning glue.	G. circulatory system
______	type of movement exhibited by dead bacteria.	H. water
		I. Brownian movement

9. Complete the following statements by filling in the numbered blanks on the right with the correct word.

(a) Particles settle out of a suspension because the force of __(1)__ is stronger than the force which holds them in suspension.
(1) ________________

(b) A colloid, in which the particles have expanded to form a network which traps water molecules, is said to be in the __(2)__ state.
(2) ________________

(c) White blood cells use a process known as __(3)__ to engulf bacteria.
(3) ________________

(d) __(4)__ is a passive process by which molecules move from an area of higher concentration to an area of lower concentration.
(4) ________________

(e) __(5)__ is the shrinking of a red blooc cell due to a loss of water when placed in a hypertonic solution.
(5) ________________

(f) __(6)__ is an active process which allows cells to take in essential, soluble materials.
(6) ________________

(g) The process by which molecules are transported across the plasma membrane against the concentration gradient is called __(7)__ __(7)__ (two words).
(7) ________________
____

(h) Water molecules will always move from the __(8)__ solution to the __(9)__ solution during osmosis. (8) ________________ (9) ________________

(i) The bursting of a cell by placing it in a hypotonic solution is called __(10)__. (10) ________________

10. List three substances which diffuse readily across cell membranes.

(a) ____

(b) ____

(c) ____

11. Why is energy, in the form of ATP, necessary for active transport?

____

____

____

____

Please check your work with the answers given on pages 27 and 28.

Homeostasis and Homeostatic Mechanisms

READ

Read the sections of your text dealing with homeostasis (pp. 6, 68 and 411).

The tendency for the body of each living organism to maintain its internal makeup is called **homeostasis**. This term was derived from the Greek words meaning "same state." Homeostasis, which results in a constant internal environment, is an essential prerequisite for normal cellular activity.

The watery environment surrounding all living cells is known as the extracellular fluid. The extracellular fluid contains gases, nutrients and ions — all necessary for the maintenance of life. For the body's cells to survive, the composition of this fluid must be precisely maintained at all times. Any disturbance of this "steady state" will result in sickness. If the composition of the body fluids is not eventually brought back into balance, cellular activities will cease, leading to the death of the organism.

Stress can be defined as any stimulus that creates an imbalance in the internal environment of an organism. Heat, cold, loud noises or even a lack of oxygen are all examples of stress that may come from the external environment. Stress may also originate within the body in the form of pain, tumors, high blood pressure or unpleasant thoughts. Most stresses encountered in everyday life are mild and routine. Occasionally, however, the body must deal with the extreme stress encountered as a result of poisoning, overexposure, severe infections or surgical operations.

Fortunately, the body has many regulating (homeostatic) devices that oppose the forces of stress and bring the internal environment back into balance. These homeostatic mechanisms give all organisms a high resistance to stress. People are able to live and work in deserts where daytime temperatures easily reach 49°C or in the Arctic, where temperatures are often well below 0°C. Yet everyone's internal body temperature remains near 37°C. The body remains in homeostasis by compensating for the external stress caused by extreme temperatures.

The mechanism used most often to maintain homeostasis is a simple, self-regulating **feedback system**. In this type of system, feedback (information) is constantly being relayed to a control centre which determines whether or not body conditions are normal. The control centre then responds appropriately, by either increasing or decreasing the activity level of a process, to maintain conditions within a normal, preset range (See Figure 14).

A feedback system will only operate if the following components are present:

(a) a **receptor** to detect change.
(b) a **control centre** which determines the appropriate action required to make adjustments.
(c) an **effector** to carry out the actions.

The three components of this system use the **nervous system** or **hormones** to transmit messages between them.

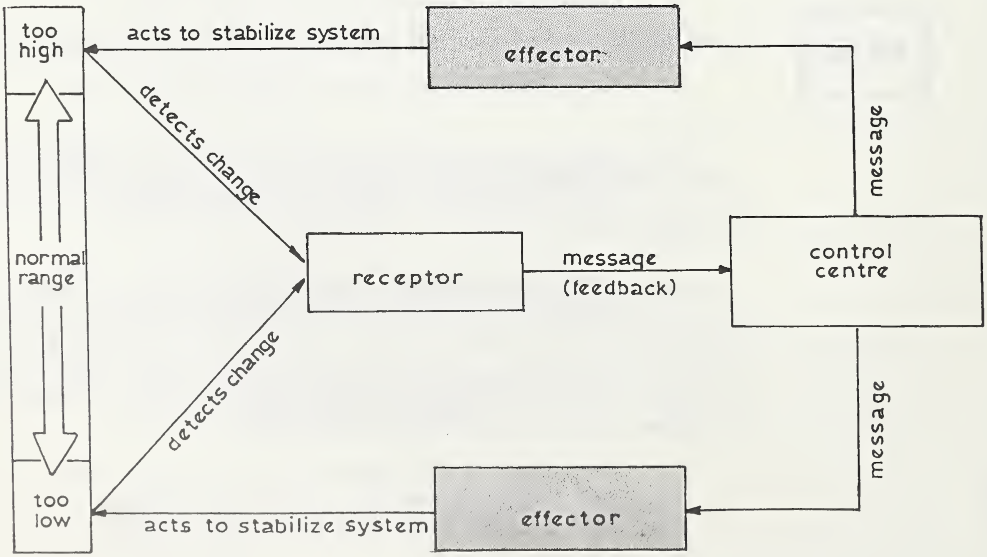
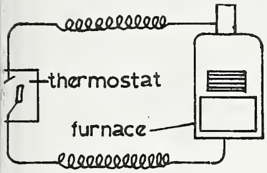


Figure 15: The components of a feedback system.

The messages being relayed to the control centre can be classified as either negative or positive feedback. **Negative feedback** tends to return the system from a swing in either direction back to the desired normal condition. **Positive feedback** causes the system to run away from the desired condition toward a complete loss of control. Positive feedback could be demonstrated by a heating system that goes on when the electrical circuit is broken or open in the thermostat. Once the heating system is turned on, the temperature would rise and the circuit would continue to remain open. Thus, the temperature would continue to rise indefinitely since the heating system would never shut off. Positive feedback relationships tend to lead to instability and therefore are quite uncommon in living things. Most biological systems are regulated, within a set range, by negative feedback.



A normal furnace will only go on if the bimetallic strip in the thermostat makes contact with the plate, thus completing the electrical circuit.

An example of negative feedback in the body occurs when the body temperature rises as a result of muscle activity while running. Active muscles produce heat which raises the temperature of the blood. A heat receptor in the brain stimulates the sweat glands in the skin, via the nervous system, to produce sweat. The evaporation of sweat cools the body and lowers the temperature of the blood. This initiates an information "feedback" to the temperature receptor in the brain which then cuts off the impulses to the sweat glands.

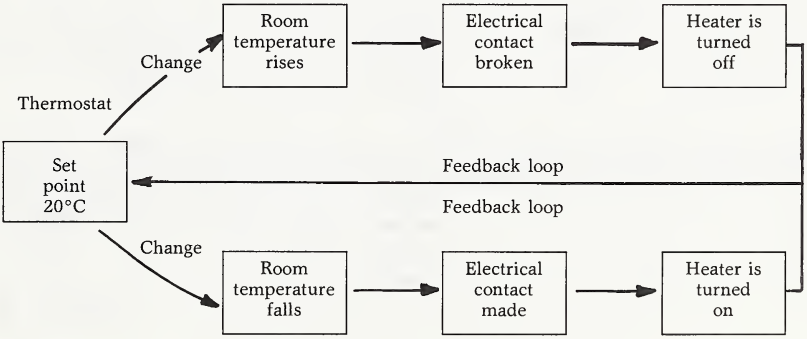


Figure 16: Normal household heating systems work using a negative feedback system. When the temperature drops below a set point a bimetallic strip in the thermostat moves in contact with a plate and completes an electrical circuit. This causes the furnace to go on. When the temperature rises above the set point, the bimetallic strip moves away from the plate, breaking the electrical circuit and turning the furnace off. Using the negative feedback system, the temperature is constantly oscillating around the set point.

pH and Buffers

A. pH

When molecules of organic acids, bases or salts are dissolved in water, they undergo **ionization** or **dissociation**, that is, they break apart into ions. An **acid** may be defined as a substance which dissociates into one or more **hydrogen ions (H^+)** and one or more negative ions. An acid then, is a substance which gives off or donates hydrogen ions (H^+). Hydrochloric acid (HCl), vinegar and lemon juice (citric acid) are all examples of acids.

A **base** or **alkali** dissociates into one or more **hydroxyl ions (OH^-)** and one or more positive ions. A base or alkali may also be a substance which will combine with, or accept, hydrogen ions. Ammonia (NH_3), lye and sodium hydroxide (NaOH) are all examples of bases.

ACID:

$$\underset{\substack{\text{carbonic acid}\\\text{(acid)}}}{H_2CO_3} \rightleftharpoons \underset{\substack{\text{hydrogen}\\\text{ion}}}{H^+} + \underset{\substack{\text{bicarbonate}\\\text{ion}}}{HCO_3^-}$$

OR

$$\underset{\substack{\text{hydrochloric}\\\text{acid}\\\text{(acid)}}}{HCl} \rightleftharpoons \underset{\substack{\text{hydrogen}\\\text{ion}}}{H^+} + \underset{\substack{\text{chloride}\\\text{ion}}}{Cl^-}$$

BASE:

$$\underset{\substack{\text{ammonia}\\\text{(base)}}}{NH_3} + \underset{\substack{\text{hydrogen}\\\text{ion}}}{H^+} \rightleftharpoons \underset{\substack{\text{ammonium}\\\text{ion}}}{NH_4^+}$$

OR

$$\underset{\substack{\text{sodium}\\\text{hydroxide}\\\text{(base)}}}{NaOH} \rightleftharpoons \underset{\substack{\text{sodium}\\\text{ion}}}{Na^+} + \underset{\substack{\text{hydroxyl}\\\text{ion}}}{OH^-}$$

Strong acids, such as hydrochloric acid (HCl), almost totally separate into H^+ ions and Cl^- ions in water. A strong base, such as sodium hydroxide (NaOH), will separate to form Na^+ ions and OH^- ions in water. When a base and an acid are combined the H^+ and OH^- ions combine to form water (H_2O). The remaining ions combine to form a salt, which in this case, would be sodium chloride (NaCl). This type of reaction is referred to as **neutralization**.

$$\underset{\substack{\text{hydrochloric}\\\text{acid}\\\text{(acid)}}}{HCl} + \underset{\substack{\text{sodium}\\\text{hydroxide}\\\text{(base)}}}{NaOH} \rightleftharpoons \underset{\substack{\text{sodium}\\\text{chloride}\\\text{(salt)}}}{NaCl} + \underset{\text{(water)}}{H_2O}$$

The number of hydrogen or hydroxyl ions in a solution will determine the acidity or basicity of that solution. The more hydrogen ions present in a solution, the more acidic the solution will be. When dealing with bases, the more hydroxyl ions present, the more basic (alkaline) the solution.

Just how many hydrogen or hydroxyl ions are in a solution is not known but an estimate can be made by calculating the concentrations of the ions in solution. The concentration of hydrogen or hydroxyl ions in a solution is expressed in moles per litre. A mole is a unit for measuring the amount of a substance in a system which combines both the weight of the molecule and the number of molecules present.

$$\text{Moles} = \frac{\text{weight in grams}}{\text{molecular weight}}$$

The concentration (moles/litre) of hydrogen ions in a solution is the basis for a scale known as pH. The term **pH** is used to describe the degree of acidity or alkalinity of a solution. The pH scale runs from 0 to 14. The lower the pH, the more acidic the solution. The higher the pH, the more basic or alkaline the solution. At the midpoint of the pH scale (7) the solution is neither acidic or basic. A solution with a pH of 7 has an equal number of hydrogen and hydroxyl ions and is considered to be **neutral**. Pure water would be an example of a neutral solution.

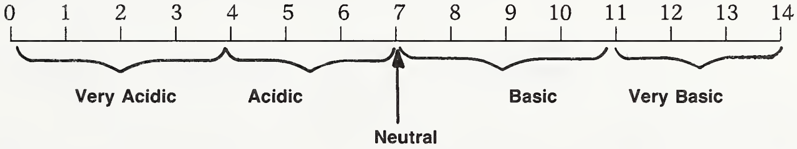


Figure 15: The pH scale of hydrogen ion concentration. Each division represents a tenfold change in acidity or alkalinity. This means that a pH of 5 is ten times more acidic than a pH of 6.

B. Buffers

The maintenance of suitable pH levels in the various body fluids is essential for good health. Each type of fluid has its own optimal pH range (See Figure 16). The pH of blood plasma and extracellular fluid is about 7.4. This pH must be kept within a range of pH 7.0 to pH 7.9 if a person is to survive.

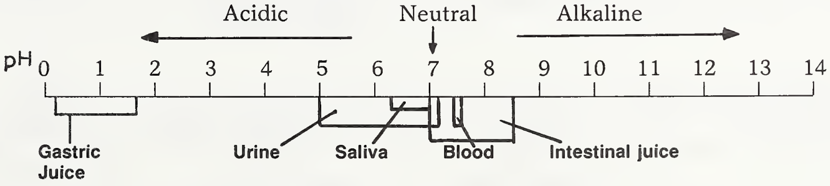


Figure 16: The normal pH ranges for various body fluids.

The pH levels of the body fluids remain relatively constant even though we may drink lemon juice with a pH of 2 or milk of magnesia with a pH of 10. The homeostatic mechanisms which maintain the pH values within the body are called **buffer systems**.

The main function of a buffer system is to react with strong acids or bases in the body and replace them with weak acids or bases. Strong acids or bases dissociate easily, flooding a solution with H^+ or OH^- ions. A flood of H^+ or OH^- ions would lead to a major change in the pH of a solution. Weak acids or bases do not dissociate so easily. They contribute fewer H^+ or OH^- ions to a solution and thus have little effect on the pH. The chemicals that change strong acids or bases into weak ones are called **buffers**.

Carbonic acid, sodium bicarbonate, phosphate ions, plasma proteins and hemoglobin are all examples of buffers found in the extracellular fluid. The pH balance of the blood plasma and extracellular fluid is, by and large, maintained by the carbonic acid — bicarbonate buffer system. Carbonic acid is a weak acid and sodium bicarbonate is a weak base. In solution, the members of this buffer pair will dissociate as follows:

Acidic component:	H_2CO_3 carbonic acid	$\rightleftharpoons$	H^+ hydrogen ion	+	HCO_3^- bicarbonate ion
Basic component:	$NaHCO_3$ Sodium bicarbonate	$\rightleftharpoons$	Na^+ Sodium ion	+	HCO_3^- Bicarbonate ion

Each component of this buffer pair has a specific role in maintaining the pH of the body fluids. Any strong acid present in the blood plasma or extracellular fluid will react with the weak base (sodium bicarbonate) to form a salt and a weak acid. Any strong base, such as sodium hydroxide, present in the body fluids will react with carbonic acid to form water and a weak base. Thus, the carbonic acid — bicarbonate buffer system reduces the effects of strong acids or bases by reacting with them to form weak acids or bases, which will not drastically affect the pH of the body fluids.

HCl Hydrochloric acid (strong acid)	+	$NaHCO_3$ Sodium bicarbonate (weak base of buffer system)	$\rightleftharpoons$	NaCl Sodium chloride (salt)	+	H_2CO_3 Carbonic acid (weak acid)
NaOH Sodium hydroxide (strong base)	+	H_2CO_3 Carbonic acid (weak acid of buffer system)	$\rightleftharpoons$	H_2O water	+	$NaHCO_3$ Sodium bicarbonate (weak base)

Remember, strong acids or bases dissociate readily in solution, flooding it with H^+ or OH^- ions. Although not shown in the above chemical equations, carbonic acid and sodium bicarbonate react with these excess ions to maintain a constant pH.

After the excess hydrogen or hydroxyl ions are removed from solution by the buffers, they may be excreted as ions through the kidneys or combined with oxygen to form water which can then be removed by the lungs. In each case, the buffers are now free to pick up more hydrogen or hydroxyl ions. That is, they can be recycled.

Enzymes

READ

Read the section of your text entitled "Enzymes" (pp. 32 and 33). You should also review the structure of proteins (pp. 333 to 335 of your text and pp. 10 to 12 of Lesson 4).

Enzyme action regulates cell metabolism. **Enzymes are catalysts** in chemical reactions taking place in the body. The following are some of the basic characteristics of enzymes which you should know.

A. Structure

Enzymes are protein molecules which can catalyze a given reaction within the body. Minerals or vitamins are often found attached to enzymes, although the majority of the enzyme is protein. The mineral or vitamin portion of an enzyme is called a coenzyme. **For more information regarding enzymes, please refer to Lesson 4, page 19.**

Each enzyme has a certain configuration or structure which allows it to bind to specific molecules. This is why each enzyme is only able to catalyze a specific reaction. This means that there must be thousands of different enzymes present in a single cell to catalyze the thousands of reactions which take place.

All of the chemical and physical changes which affect proteins also affect enzymes. If the temperature, pressure or acidity (pH) changes to any appreciable extent, the enzyme might not be able to function. The enzyme is then said to be **denatured**. If these effects are mild and only occur over a short time, the protein can recover and return to its natural state. However, if conditions are harsh and lasting then the denaturation becomes permanent and irreversible. Such a condition is called **coagulation**. For example, you cannot uncook an egg.

Usually enzymes are named after the kind of molecule they affect with the suffix 'ase.' For example, an enzyme digesting the disaccharide maltose would be called maltase. In addition, the action carried out on a substrate can be used in naming the enzyme; e.g. dehydrogenase.

B. Function

Enzymes permit chemical reactions to occur under the normal temperatures found in organisms. Chemical reactions occur when molecules collide with each other. The energy required to produce a collision powerful enough to bring about a chemical reaction is known as the **energy of activation**. Under laboratory conditions, energy of activation for chemical reactions is reached easily by just heating the substances. Living organisms, on the other hand, cannot tolerate extreme temperatures since they function best within a narrow temperature range. To bring about chemical reactions, biological systems use enzymes instead of heat to increase the rates of molecular collisions. Enzymes **lower** the energy of activation and permit reactions to occur at lower temperatures than would be required if they were carried out in a test tube.

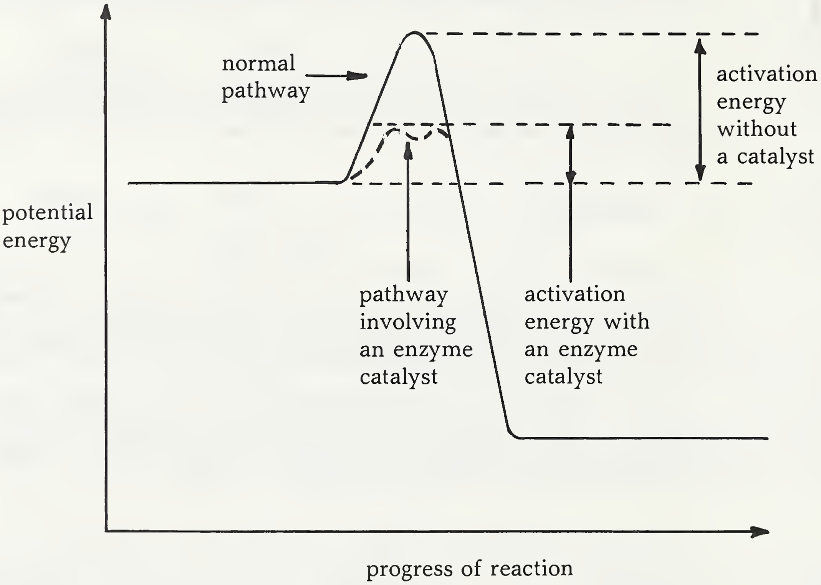


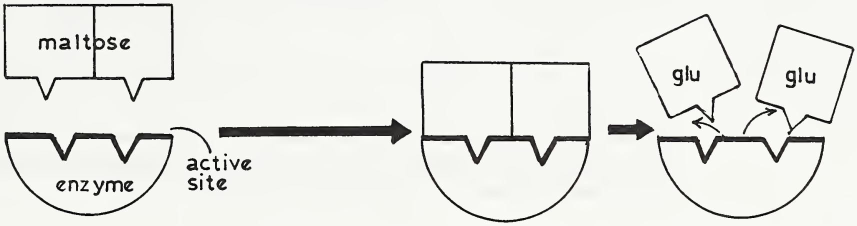
Figure 17: Enzymes lower the activation energy required for a reaction to take place. This lower activation energy allows reactions to proceed at normal body temperatures. In short, this means that the body is able to speed up reactions by using enzymes instead of an external heat source, like a match or bunsen burner.

An enzyme combines temporarily with a substrate to form an enzyme-substrate complex. The enzyme has a particular shape, with a unique platform where the **substrate** (reacting molecule or molecules) can be trapped. In turn, the substrate has to have a particular shape to fit on this platform. This is known as the **lock-and-key** theory.

The enzyme remains passive as it provides the platform for the substrates to react. Once the reaction is completed, the enzyme is free to combine with more substrate molecules. Thus, the enzyme speeds up the rate of reactions but does not determine the direction of the reaction or enter into the reaction itself.

Since an enzyme is basically a protein, it tends to be a huge molecule compared to the substrate. Consequently, only a small part of the enzyme may be involved in a particular reaction. This part is called the **active site**.

$$\underset{\text{(substrate)}}{\text{maltose}} \xrightarrow[\text{(enzyme)}]{\text{maltase}} \underset{\text{(product 1)}}{\text{glucose}} + \underset{\text{(product 2)}}{\text{glucose}}$$



Enzyme + substrate

Enzyme • Substrate complex

Enzyme + products

Figure 18: Enzyme action

Enzymes are required in only small amounts as a single enzyme is used over and over again.

Factors Affecting Enzyme Activity

A. Temperature

The rate of enzyme action is increased with a gradual increase in temperature up to an **optimum temperature**. This temperature varies somewhat for various enzymes but is usually around the normal body temperature (37°C). For example, in humans the optimum temperature range is between 35°C and 40°C. Most enzymes cease to function at temperatures from 55°C to 60°C. Higher temperatures (+ 100°C) will result in the denaturation of the proteins which make up the enzyme, permanently inactivating it.

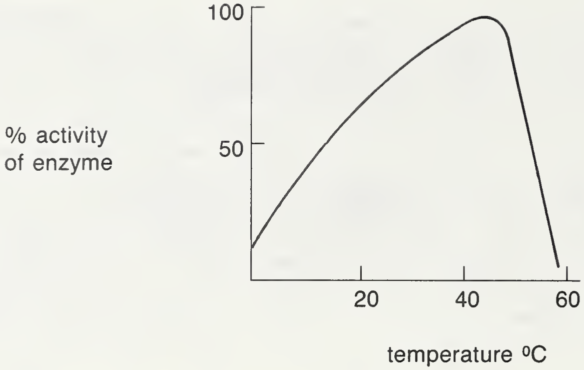


Figure 19: **Enzyme activity increases, as the temperature increases, to a point just above normal body temperature. Enzyme activity drops off at higher temperatures due to the denaturation of the enzyme's protein structure.**

B. pH

Each enzyme has its own optimum pH. For example, salivary amylase works best at a slightly alkaline pH just above 7. The protein digesting enzymes of the stomach work best in a pH range of 1 to 3.

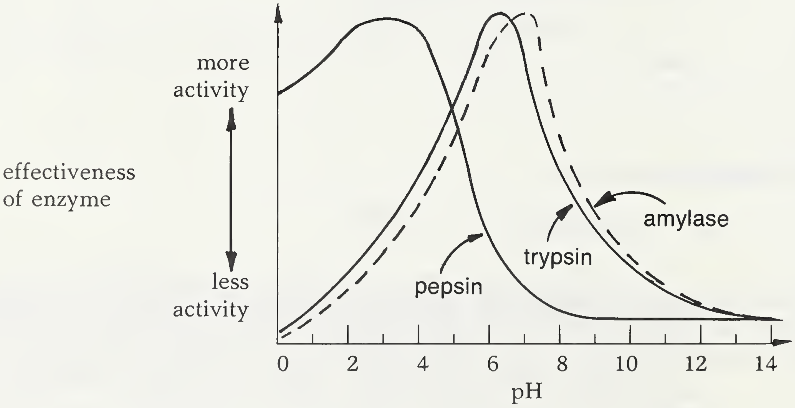
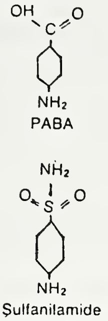


Figure 20: **pH and enzyme activity. Notice that each enzyme has its own optimal pH.**



Competitive Inhibition of PABA by a sulfa drug

C. Competitive Inhibitors

In addition to heat and acidity, enzymes may have their activity limited or reduced by other factors. Poisons such as mercury or cyanide may inhibit enzyme activity. Cyanide inhibits the use of oxygen by the cell.

Competitive inhibitors also inhibit cellular activity. These substances block normal enzymatic actions because their molecular structure is very similar to the actual substrate. Essentially they compete with a substrate for the active site on the enzyme; consequently, the enzyme becomes inactive. Sulfa drugs are one example of a competitive inhibitor. Sulfa drugs (such as sulfanilamide) are able to stop some bacterial infections because they are structurally similar to PABA (para-aminobenzoic acid) which is necessary for bacterial growth. Sulfanilamide becomes attached to the bacterial enzyme and occupies the place PABA would usually have. As a result, no reactions with PABA can take place and the bacteria are unable to grow.

Exercise 2

1. Match the following by choosing the correct letter from column II and placing it in the appropriate blank in column I. **DO NOT** use any letter more than once.

	Column I	**Column II**
______	detects changes in normal body conditions	A. homeostasis
______	tends to return a system back to the desired normal condition	B. receptor
______	monitors a system and initiates actions to maintain homeostasis	C. brain
______	any stimulus that creates an imbalance in the internal environment of an organism	D. control centre
______	often used to transmit messages between the components of a feedback system	E. effector
______	causes a system to run away from the desired normal condition	F. negative feedback
______	carries out the actions required to stabilize the system	G. nervous system
______	tendency for an organism to maintain its internal environment	H. positive feedback
		I. stress

2. Complete the following statements by filling in the numbered blanks on the right with the correct answer.

   (a) When acids or bases are dissolved in water, they undergo __(1)__, that is, they break apart into charged particles known as __(2)__.

   (1) ____________________

   (2) ____________________

   (b) An acid is a substance which gives off or donates __(3)__ ions.

   (3) ____________________

   (c) In a neutralization reaction an acid and a base react to form __(4)__ and __(5)__.

   (4) ____________________

   (5) ____________________

   (d) A base or alkali dissociates into one or more __(6)__ ions and one or more positive ions.

   (6) ____________________

   (e) A solution with a pH of 7 is considered to be __(7)__.

   (7) ____________________

   (f) The chemicals that change strong acids or bases into weak ones are called __(8)__.

   (8) ____________________

   (g) The __(9)__ __(9)__ — bicarbonate buffer system maintains the pH of the blood plasma and extracellular fluid.

   (9) ____________________

   ____

   (h) The __(10)__ and the __(11)__ are organs which will excrete excess hydrogen or hydroxyl ions so that the buffers can be recycled.

   (10) ____________________

   (11) ____________________

True/False. Circle the letter **T** or **F** to indicate whether the statement is true or false.

3. All enzymes are proteins. T F
4. An increase in temperature to 37°C would denature enzymes. T F
5. All enzymes work best at a pH of 7. T F
6. One type of enzyme catalyzes one type of reaction. T F
7. Enzymes are recycled in the body. T F
8. The actual site of enzymatic action is called the substrate platform. T F
9. Enzymes lower the energy of activation of a cellular reaction. T F
10. The lock-and-key theory describes the interaction of enzyme and substrate. T F
11. Boiling would increase the rate of enzyme action. T F
12. Substrate ''look-alikes'' may compete for active sites on an enzyme. T F

Check your work with the answers given on pages 28 and 29.

ANSWERS TO THE KEYED EXERCISES

Exercise 1, pp. 13-15

Circle the word which will best complete the following statements.

1. The movement of ammonia molecules from a bottle to the far corner of a room would be an example of ([✓ diffusion]/dialysis/osmosis).
2. The smaller the molecule, the ([✓ faster]/slower) its movement.
3. A membrane which would **not** allow any molecules to pass through would be ([✓ impermeable]/semipermeable/permeable).
4. If water passes back and forth through a cell membrane, the solution outside the membrane is probably (hypotonic/hypertonic/[✓ isotonic]) to the solution within the membrane.
5. A membrane which allows sugar molecules to pass through, but not protein molecules, would be a demonstration of (diffusion/osmosis/[✓ dialysis]).
6. A cell contains 10 micromoles of sodium ions in the cytoplasm and 8 micromoles of sodium ions in the extracellular fluid. Sodium ions continue to enter the cell by the process of (osmosis/dialysis/[✓ active transport]/passive transport).
7. Active transport differs from passive transport because it requires (a concentration gradient/a movement of molecules/[✓ energy]).
8. Match the following statements with the items given on the right.

	Column I
D	the watery environment surrounding each cell
E	type of mixture in which the solutes are dissolved in a solvent
H	the universal solvent of all living things
A	type of mixture in which the particles settle out
G	transports nutrients and wastes to and from the cells
C	term derived from the Greek word meaning glue
I	type of movement exhibited by dead bacteria

Column II

A. suspension
B. cytoplasm
C. colloid
D. extracellular fluid
E. solution
F. osmosis
G. circulatory system
H. water
I. Brownian movement

9. Complete the statements with the words given below.

(1) **gravity**
(2) **gel**
(3) **phagocytosis**
(4) **Diffusion**
(5) **crenation**
(6) **Pinocytosis**
(7) **active transport**
(8) **hypotonic**
(9) **hypertonic**
(10) **cytolysis**

10. List three substances which diffuse readily across cell membranes.

Water, glucose, carbon dioxide, oxygen and some minerals diffuse readily across the cell membrane.

11. Why is energy, in the form of ATP, necessary for active transport?

Energy is needed to move molecules against the concentration gradient, that is, from a region of lower concentration to a region of higher concentration.

Exercise 2, pp. 25 and 26

1. Match the following statements with the items given on the right.

	Column I
B	detects changes in normal body conditions
F	tends to return a system back to the desired normal condition
D	monitors a system and initiates actions to maintain homeostasis
I	any stimulus that creates an imbalance in the internal environment of an organism
G	often used to transmit messages between the components of a feedback system
H	causes a system to run away from the desired normal condition
E	carries out the actions required to stabilize the system
A	tendency for an organism to maintain its internal environment

Column II

A. homeostasis
B. receptor
C. brain
D. control centre
E. effector
F. negative feedback
G. nervous system
H. positive feedback
I. stress

2. Complete the statements with the words given below.

(1) **dissociation**
(2) **ions**
(3) **hydrogen**
(4) **salt**
(5) **water**
(6) **hydroxyl**
(7) **neutral**
(8) **buffers**
(9) **carbonic acid**
(10) **kidneys**
(11) **lungs**

True or False

3. **True.**

4. **False.** Enzymes usually work best at body temperature, 37°C.

5. **False.** Enzymes have a wide range of pH optimums.

6. **True.**

7. **True.**

8. **False.** The ''active site'' is the site of enzyme-substrate interaction.

9. **True.**

10. **True.**

11. **False.** Boiling denatures an enzyme.

12. **True.**

EXERCISES TO BE SENT IN FOR CORRECTION

Part One: Multiple Choice

For each of the following questions, choose the best answer and write the appropriate letter in the blank provided.

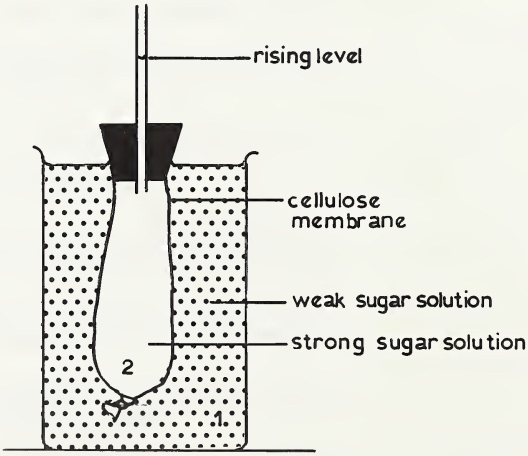
_____ 1. The ability of some cells to move substances across the plasma membrane against a concentration gradient is called

(a) diffusion.
(b) Brownian movement.
(c) active transport.
(d) selective permeability.

_____ 2. The type of membrane that allows only certain molecules to pass through it is called

(a) permeable.
(b) pinocytic.
(c) porous.
(d) semipermeable.

Use the following diagram to answer questions 3 and 4.



_____ 3. Which of the following would cause the strong sugar solution to rise up in the glass tubing?

(a) water passing from 1 to 2
(b) water passing from 2 to 1
(c) sugar passing from 1 to 2
(d) sugar passing from 2 to 1

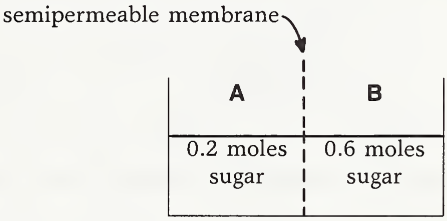
______ 4. In the osmotic system shown, water molecules would move

(a) from the hypotonic to the hypertonic solution.
(b) from the hypertonic to the hypotonic solution.
(c) randomly, remaining in the beaker outside the membrane.
(d) from a region of lower concentration to a region of higher concentration.

______ 5. Some fish are able to live in water which is hypotonic compared to their body cells. One explanation for their survival might be that

(a) a large amount of water is taken into the digestive system.
(b) a large amount of watery urine is produced.
(c) salt is eliminated in the urine.
(d) salt is retained by the digestive tract.

Use the osmotic system given below to answer questions 6 and 7. The membrane is permeable to both sugar and water.



______ 6. The initial movement of water would be

(a) from side A to side B.
(b) from side B to side A.
(c) an equal movement from side to side.
(d) no net movement.

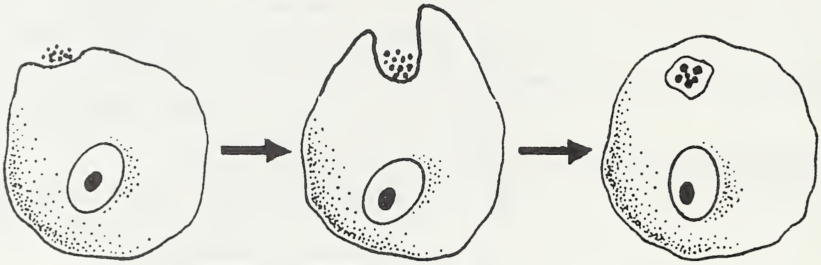
______ 7. At the end of several hours, the concentration of sugar on each side of the membrane would be:

(a) 0.2 moles on side A and 0.6 moles on side B.
(b) 0.3 moles on side A and 0.3 moles on side B.
(c) 0.4 moles on side A and 0.4 moles on side B.
(d) 0.8 moles on side B.

______ 8. Carbon dioxide moves from the blood into the lungs by the process of

(a) active transport.
(b) diffusion.
(c) osmosis.
(d) carrier-facilitated diffusion.

Use the following diagram to answer question 9.

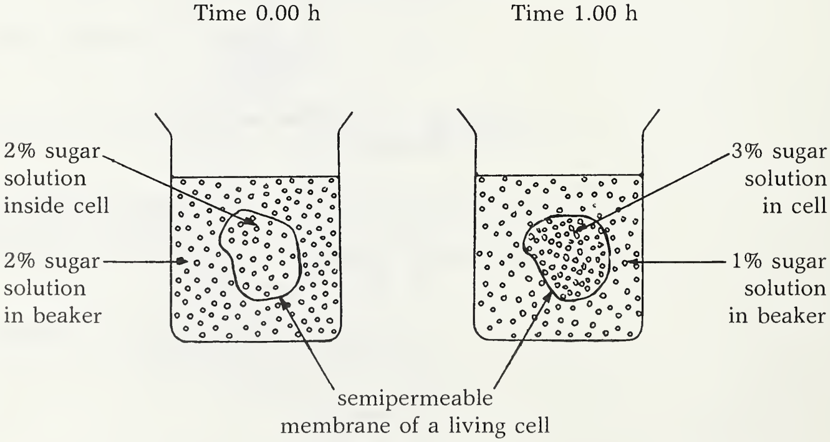


_____ 9. Substances were able to cross the cell membrane by the process known as

(a) active transport.
(b) Brownian movement.
(c) pinocytosis.
(d) phagocytosis.

Use the following information to answer question 10.

Movement of Substances Across the Membrane of a Living Cell


Time 0.00 h
Time 1.00 h
2% sugar solution inside cell
2% sugar solution in beaker
3% sugar solution in cell
1% sugar solution in beaker
semipermeable membrane of a living cell

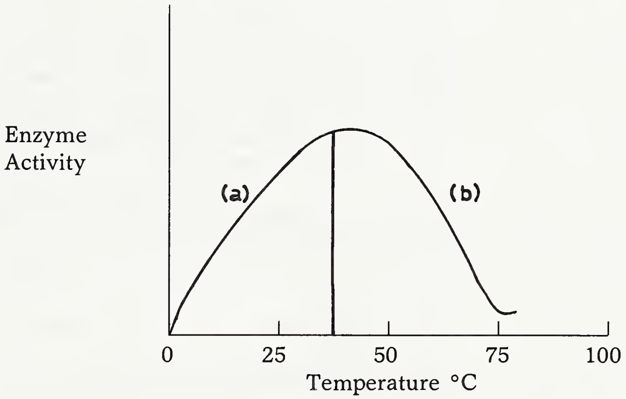
_____ 10. What process would account for the increase in the concentration of sugar within the cell after one hour?

(a) osmosis
(b) diffusion
(c) ionic attraction
(d) active transport

______ 11. Homeostasis is a condition in which

(a) the internal environment of an organism is the same as the external environment.
(b) the amount of food entering the digestive system equals the amount of waste eliminated.
(c) all the organism's bodily functions are static despite changes in the external environment.
(d) the internal environment of the organism is maintained in a state of equilibrium despite changes in the external environment.

The graph below illustrates how enzyme action varies with temperature. Use this information to answer questions 12 to 14.



______ 12. The **optimum temperature** for this enzyme is closest to

(a) 0°C.
(b) 25°C.
(c) 35°C.
(d) 50°C.

______ 13. The graph is increasing on side (a) because

(a) more enzyme-substrate interactions are taking place.
(b) more enzymes are being formed.
(c) a greater amount of substrate has just entered the reaction.
(d) more product is leaving the reaction.

______ 14. Side (b) of the graph decreased because

(a) less enzyme is being synthesized.
(b) the enzyme is being denatured.
(c) all enzyme "active sites" are occupied.
(d) less substrate is available for the reaction.

______ 15. Competitive inhibitors slow the action of enzymes because they

(a) denature the enzyme.
(b) have almost the same shape as the enzyme.
(c) can occupy the active site of the enzyme.
(d) break the amino acid bonds.

______ 16. An enzyme which works best in an acidic solution would operate best in a solution with a pH of

(a) 2.
(b) 7.
(c) 8.
(d) 11.

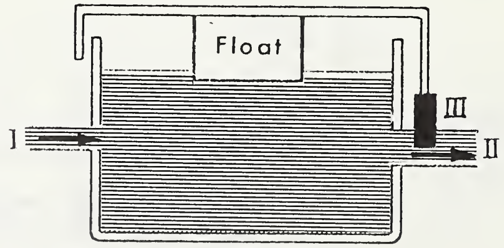
______ 17. What is the activation energy of a reaction?

(a) the energy given off during a chemical reaction
(b) the energy needed to start a chemical reaction
(c) the energy absorbed during a chemical reaction
(d) a type of solar energy

______ 18. Jello is a common, jelly-like desert which many people enjoy. This substance can be classified as a

(a) solution.
(b) suspension.
(c) colloid.
(d) semipermeable membrane.

Use the following diagram to answer question 19.



______ 19. In order for the model to maintain a dynamic equilibrium (steady state), it is necessary that

(a) III close as the flow at I increases.
(b) III regulate the flow at II.
(c) the flow at II be greater than at I.
(d) the flow at I be independent of the flow at II.

______ 20. If a fresh water plant is put into a saturated salt solution, the cells of the plant probably would

(a) take in more fluid.
(b) lose fluid.
(c) show no effect.
(d) take in salt.

Part Two: Matching and Fill in the Blanks

1. Match the following by choosing the correct letter from column II and place it in the appropriate blank in column I. **Do not** use any letter more than once.

	Column I	**Column II**
______	produced when a base dissociates in water	A. a salt
______	one of the products of a neutralization reaction involving an acid and a base	B. hydroxyl ions
		C. neutral
______	solution with a pH of 7	D. base
______	mechanisms which maintain pH values of body fluids	E. acid
______	solution with a pH of 2	F. bicarbonate ions
______	term used to describe the acidity or basicity of a solution	G. hydrogen ions
		H. enzymes
______	produced when an acid dissociates in water	I. pH
______	solution with a pH of 9	J. buffer systems

2. Complete each of the following statements by filling in the numbered blank on the right.

(a) The maintenance of a stable or constant environment conducive to cellular activity is called __(1)__.
(1) ______________

(b) Extracellular fluid, the liquid medium surrounding each cell, is actually a derivative of the __(2)__ __(2)__ (two words).
(2) ______________
____

(c) Molecules are constantly in motion because of the movement of their __(3)__.
(3) ______________

(d) A solution is made up of the dissolved substances, the __(4)__, and the substance in which they are dissolved, the __(5)__.

(4) ____________________

(5) ____________________

(e) Cytolysis will occur if a red blood cell is placed in a __(6)__ solution.

(6) ____________________

(f) Projections of the cytoplasm that surround solid particles during phagocytosis, are known as __(7)__.

(7) ____________________

(g) Wastes, large proteins and fat droplets are all able to exit the cell by a process known as __(8)__.

(8) ____________________

(h) Enzymes lower the __(9)__ __(9)__ of reactions, permitting them to occur at lower temperatures.

(9) ____________________

____

(i) Excess ions, removed from the body fluids by buffers can be excreted by the lungs or the __(10)__.

(10) ____________________

(j) The part of the enzyme involved in a reaction is called the __(11)__ __(11)__ (two words).

(11) ____________________

____

(k) Enzyme activity drops off at higher temperatures, the result of a __(12)__ of proteins.

(12) ____________________

(l) Heat, cold and loud noises are all examples of __(13)__ __(13)__ (two words).

(13) ____________________

____

(m) Messages can be transmitted between the components of a feedback system using either the __(14)__ __(14)__ or __(15)__.

(14) ____________________

____

(15) ____________________

Part Three: Short Answer

1. What is the main function of a buffer system?

____

____

____

____

____

2. (a) Suppose the concentration of an essential metabolic substance was lower outside of the cell than inside the cell. Yet this substance is required by the cell to carry out an activity. How would the substance get into the cell?

   (b) Explain briefly how the above process works.

3. Briefly explain the negative feedback system used by humans to lower body temperature when we "overheat."

4. Briefly explain why each cell in the human body contains thousands of different enzymes but only limited quantities of each type.

Part Four: Laboratory Investigation

Purpose

To observe the functioning of a selectively permeable membrane.

Background

In this investigation, you will see how certain molecules pass in and out of cells. The cell membrane is a selectively permeable membrane. Selectively permeable or semipermeable membranes permit only certain substances to pass through and not others. In this experiment you will be using a nonliving membrane (dialysis tubing) which is semipermeable though not as complex as that of living cells.

Benedict's solution (blue in color) is added to the substance to be tested and then heat is applied. If simple sugars are present, the blue color will change to any of the following colors; light green, yellow, orange, red or brown. The more sugar there is, the darker the solution will be. A failure to change from the original blue after heating means that the solution **does not** contain any simple sugars. Glucose is a simple sugar.

The presence of complex carbohydrates like starch can be identified with a **dilute iodine solution**. A change to a blue-black color is a positive test for the presence of starch in a substance.

Materials Required to Complete the Investigation

- two beakers (250 ml) or clear glass jars
- hot water bath
- two - 13 × 100 mm test tubes (small)
- starch suspension (Mix one teaspoon of corn starch with 50 ml of water)
- a test tube holder
- Glucose solution (Dissolve one teaspoon of glucose in 10 ml of warm water)
- Iodine solution
- Benedict's solution
- Dialysis tubing
- string or strong thread
- a medicine dropper
- water

Caution: Iodine solution and Benedict's solution are both poisonous if taken internally.

Note: The chemicals used in this laboratory investigation are also required to complete the experiments in lesson 4. After completing the experiments in lesson 2 and lesson 4, refer to p. 11 of the Introduction to Biology 30. This describes the correct methods of safely disposing the chemicals used in these laboratory investigations.

Procedure

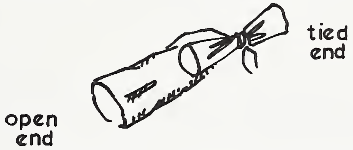
As you are performing this exercise try to keep in mind the relationship between what is happening in the exercise and similar processes in cells.

Prepare a glucose solution by dissolving one teaspoon of glucose in 10 ml of warm water.

Prepare a starch suspension by mixing one teaspoon of corn starch with 50 ml of warm water.

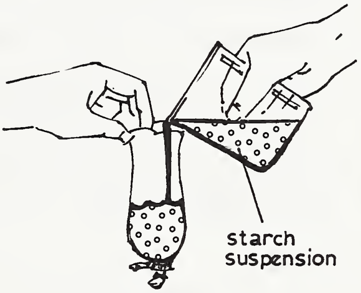
Soak a 15 cm section of dialysis tubing **in warm water** for a few minutes. Gently rub the ends between your fingers to separate the layers. The tube may be opened by rolling it between your thumb and forefinger. Blowing gently into the tube will also separate the layers.

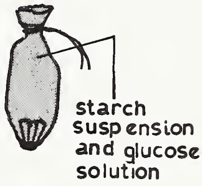
Tie one end securely. To obtain a tight seal, flip part of the end over and tie it securely with the string as illustrated.



Fill the dialysis tubing ½ full with starch suspension. Be sure to **stir up the starch suspension** just before pouring it into the dialysis tube. Now **add the 10 ml of glucose solution** to the dialysis tube containing the starch suspension.

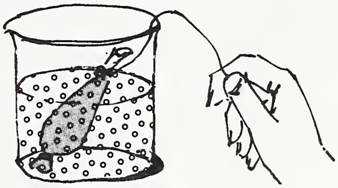
Twist the top of the dialysis tubing shut and **tie it** tightly with string. Leave a loose piece of string 10-15 cm long. You should now have a sausage shaped bag containing the starch suspension and the glucose solution.




starch suspension and glucose solution

Rinse the bag off by holding it under warm running water from a kitchen or bathroom faucet.

Fill a clean, 250 ml plastic beaker with warm water and place the bag containing the glucose and starch mixture into the beaker. Leave the string outside the beaker.



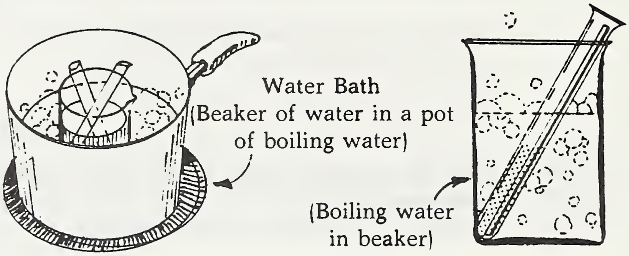
Record the time of day when you place the dialysis tube in the beaker, then set the beaker aside for 20 minutes.

During the 20 minute wait, set up a **hot water bath** by bringing a small pot of water to a gentle boil on your stove. (You may also boil your water in a kettle.)

After 20 minutes withdraw an eye dropper full of water from the beaker. Place this in a clean test tube and **add 10 drops of Benedict's solution.**

Heat this test tube in the hot water bath for 10-15 minutes. Be sure and exercise a degree of caution when working with the hot water bath. Hot water, steam and hot glassware can cause burns.

Caution: Do not place plastic beaker directly on burner.



Water Bath
(Beaker of water in a pot of boiling water)

(Boiling water in beaker)

Record your observations on the table provided.

Withdraw another eyedropper full of water from the beaker and place this in a clean test tube.

Add 12 drops of dilute iodine solution to the test tube and **record** the initial color of the solution on the table provided.

Let the water and iodine solution stand for 10 minutes, and **record** the color of the solution on the table provided.

Results

Substance Tested	Color Observed	
	Before Heating	After Heating
Beaker Water and Benedict's Solution		
	Initial (Time 0)	After 10 Minutes
Beaker Water and Iodine Solution		

Analysis

1. Why was it important to rinse the dialysis bag before placing it in the beaker of warm water?

2. Did diffusion through the semipermeable membrane take place in this Investigation?

   ____

   If so, explain how you determined this.

   ____

   ____

   ____

   ____

   ____

3. What substance was used to test for the presence of

   (a) Glucose - ________________________________

   (b) Starch - ________________________________

4. What evidence, if any, did you find which indicated that the dialysis tubing was selectively permeable?

   ____

   ____

   ____

   ____

   ____

Please submit pages 30 to 41 for correction.

END OF LESSON 2

LESSON RECORD FORM

3230 Biology 30
Revised 03/89

FOR STUDENT USE ONLY

Date Lesson Submitted ____________________

Time Spent on Lesson ____________________

(If label is missing
or incorrect)

File Number ____________________

Lesson Number __________

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Additional Grading E/R/P Code: __________

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ALBERTA CORRESPONDENCE SCHOOL

MAILING INSTRUCTIONS FOR CORRESPONDENCE LESSONS

1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

First Class

Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

OBJECTIVES

If you conscientiously complete the prescribed program of work contained in this lesson, you will be capable of carrying out the following correctly.

1. **Identify** the location of the salivary glands in human beings.
2. **Compare** the structures of the complete and incomplete digestive system.
3. **Identify** the components of the digestive system of human beings.
4. **Differentiate** between the cardiac and pyloric sphincters.
5. **Identify** special structural features of the stomach.
6. **Outline** the structure of the small and large intestines.
7. **Identify** the location and functional significance of the accessory digestive organs.

THE HUMAN DIGESTIVE SYSTEM

Introduction

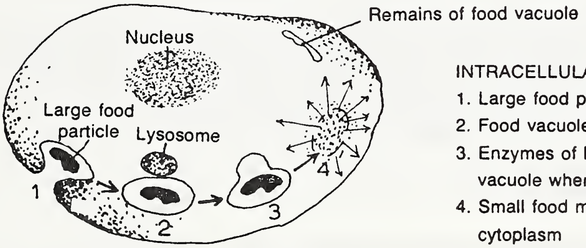
This lesson is about the digestive system. The cells, tissues, organs and organ systems of multicellular organisms cannot function properly unless they are well supplied with food and energy. Similarly, unicellular organisms require food and energy in order for them to function properly.

In Lesson 5 of this course you will study the **process** by which the digestive system provides food and energy for growth and repairs — that is, the process of digestion. In that lesson you will become more conversant with the fact that the process of digestion involves the breakdown of large, complex food molecules into smaller molecules that can be used by the organism.

Before we study the human digestive system, let us take a brief look at the digestive systems of several smaller and less complex organisms.

The Amoeba

The single celled protist, the amoeba, does not have any permanent body structures which could be called a digestive system. The organism carries out digestion within its cell, usually within food vacuoles.



INTRACELLULAR DIGESTION

1. Large food particle is ingested
2. Food vacuole is formed
3. Enzymes of lysosome enter food vacuole where hydrolysis occurs
4. Small food molecules diffuse into cytoplasm

Figure 1: Digestive Process of the Amoeba

The amoeba simply flows around its food, surrounds it (phagocytosis) and forms a small space filled with the food plus some fluids. This is the formation of a food vacuole. Digestive enzymes inside the cell now enter the food vacuole and break down the food into usable molecules which are absorbed. Indigestible wastes are eliminated by exocytosis. Digestion which occurs inside the cell is called **intracellular digestion**.

The Hydra

An animal with a digestive system somewhat more complex than that of the amoeba is the hydra. The crude digestive system of the hydra consists of a cavity (gastrovascular cavity) that opens to the outside through an opening called the mouth. Food is ingested through the mouth and into the gastrovascular cavity. Digestion and absorption occur here. All indigestible wastes are eliminated from the **gastrovascular cavity** via the mouth. A digestive system such as that of the Hydra with only one opening, the mouth, for the intake of food as well as the elimination of wastes is referred to as an **incomplete** digestive system.

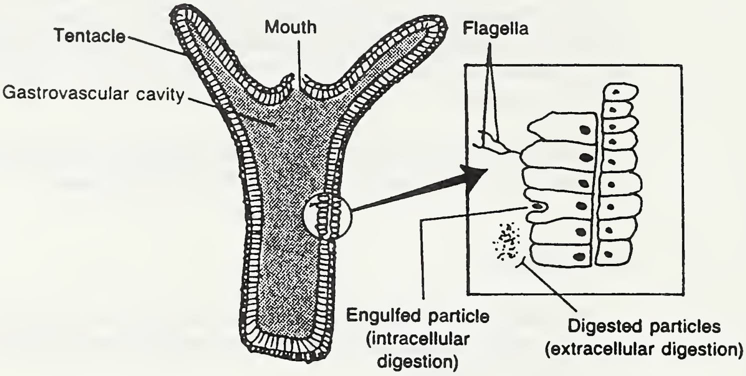

Tentacle
Mouth
Flagella
Gastrovascular cavity
Engulfed particle (intracellular digestion)
Digested particles (extracellular digestion)

Figure 2: Ingestion and Digestion in the Hydra

The majority of animals that you will read about or become familiar with have complete digestive systems. Such animals have an anterior opening called the mouth through which food is ingested. There is also a posterior opening through which waste is eliminated. Unlike the situation in the amoeba, complete digestion occurs outside the body cells but inside the cavity of the gut or digestive tract. This type of digestion is called **extracellular digestion** and occurs in all complex multicellular animals.

The Roundworms

Amongst multicellular animals, the first ones to have a complete digestive system are the parasitic roundworms. In the roundworm Ascaris, the digestive tract consists of a tube with a mouth at the anterior end and an anus at the posterior end. This parasite lives in the large intestine of pigs and humans and ingests digested food directly from its host.

The Arthropods (e.g. Grasshopper)

Still more complex is the digestive system of the group of animals called arthropods. The grasshopper has a three part digestive system. The anterior part is called the **foregut**. The **foregut** serves as a food storage area and a factory for grinding food. The central or middle part is called the **midgut**. This is where food is digested and absorbed. The **hindgut** is the posterior part of the digestive system which contains indigestible waste products. The hindgut, it is believed, serves to transport waste products to the anus. Just posterior to the **mouth**, a small, slightly enlarged area of the tube forms the **pharynx**. Near the anus, the tube enlarges to form the **rectum**.

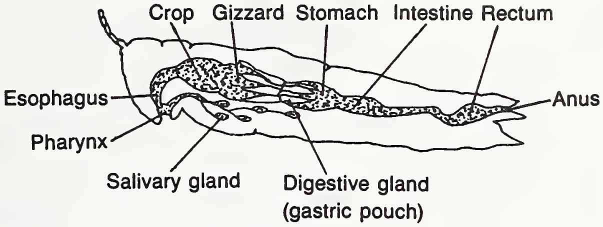


Figure 3: Digestive System of the Grasshopper

Please read the section in your text dealing with the digestive system (pp. 301-320). Pay special attention to all illustrations.

The Human Digestive System

Human beings require a complex digestive system to break down large food molecules into their products which are small enough to pass through plasma membranes to reach the cytoplasm inside cells. For example, the human digestive system reduces carbohydrates to their end product - **glucose**; proteins are reduced to their end products - **amino acids**; and fats and oils are reduced to **fatty acids** and **glycerol**. More precisely, the digestive process carried out by the organs of the digestive system function to alter the physical and chemical properties of food so that they can be absorbed into the bloodstream. These processes are the focus of Lesson 5.

The human digestive system may be described as a tube that fits into a second tube - the body cavity. This digestive system extends from the mouth to the anus. The components of the system are the **mouth, pharynx, esophagus, stomach, small intestine** and **large intestine**. There are accessory organs of the digestive system which include the **liver, gallbladder** and the **pancreas.**

The Mouth

The mouth or oral cavity consists of the **cheeks** which form the **sidewalls**, the **tongue and its muscles** which form the **floor** and the **palate** which forms the **cavity's roof**. The palate consists of **two parts**: the **hard palate** forming the **anterior part of the roof**, and the muscular **soft palate forming the posterior edge** of the **hard palate**. As indicated in your textbook, the soft palate hangs down from the posterior edge of the hard palate. The **uvula** extends downward from the free border of the soft palate. Please study the drawing on page 306 of your textbook.

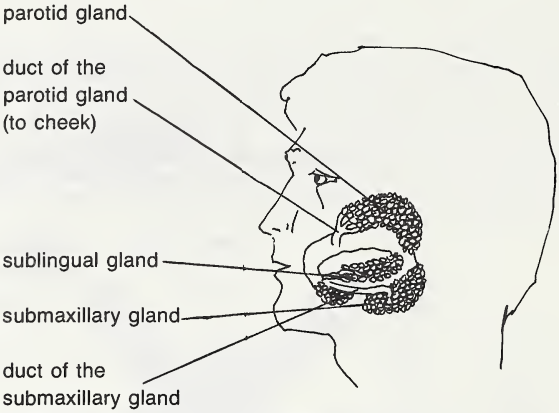

parotid gland
duct of the parotid gland (to cheek)
sublingual gland
submaxillary gland
duct of the submaxillary gland

Figure 4: Salivary Glands in Human Beings

Accessory organs in this first part of the digestive tract are the three pairs of salivary glands. Ducts leading from all three pairs empty saliva into the cavity of the mouth. In terms of location, one pair lies on the sides of the face just below and in front of each ear. These are the **parotid glands**. The disease called **mumps**, as you may be aware, is an infection of the parotid glands causing extreme swelling and irritation. The **submaxillary glands** lie between the angles of the lower jaw while the **sublingual glands** are located in the floor of the mouth, just anterior to the submaxillary glands.

The Pharynx (far-ingks) or Throat

The mouth cavity opens into the back of the throat, the **pharynx**. The pharynx serves as a passageway for air (the respiratory system) and as a passageway for food (the digestive system). It follows that the mouth and nasal cavities open into the pharynx. At the pharynx, a muscular flap called the epiglottis covers the opening of the air passage - the glottis of the respiratory system.

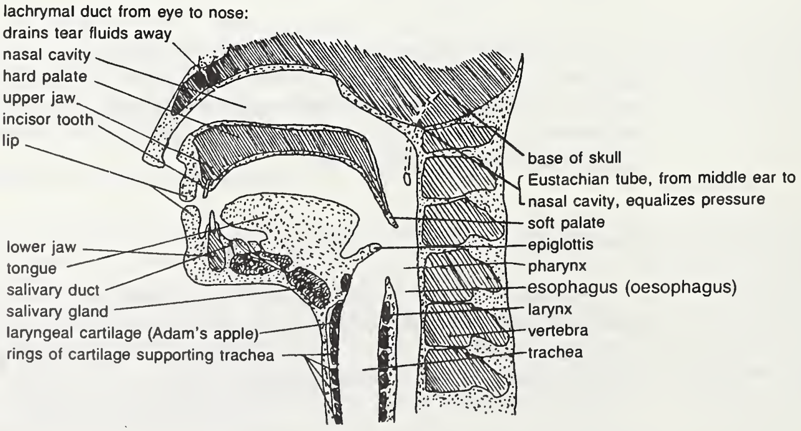

lachrymal duct from eye to nose: drains tear fluids away
nasal cavity
hard palate
upper jaw
incisor tooth
lip
lower jaw
tongue
salivary duct
salivary gland
laryngeal cartilage (Adam's apple)
rings of cartilage supporting trachea
base of skull
Eustachian tube, from middle ear to nasal cavity, equalizes pressure
soft palate
epiglottis
pharynx
esophagus (oesophagus)
larynx
vertebra
trachea

Figure 5: Vertical Section Through the Mouth and Throat Region

The epiglottis closes when food or water is being swallowed, keeping such materials out of the air passage.

The Esophagus (e-sof-a-gus) or Gullet

The esophagus represents the third part of the digestive system. It is a muscular, collapsible tube that descends behind the trachea (windpipe) from the pharynx. Passing downward through the muscular diaphragm, this 23 cm to 25 cm tube opens immediately into the stomach. From the esophagus, food enters the stomach with the aid of muscles in the walls of the esophagus. The esophagus **does not** produce digestive enzymes and does not carry out absorption. Primarily, it secretes mucus and transports food to the stomach. Solid or semi-solid foods take from 4 to 8 seconds to travel from the mouth to the stomach via the esophagus. Liquids and very soft foods pass through in about one second.

Just above the diaphragm, and before entering the stomach, the esophagus narrows to form a sphincter (SFINGK-ter). A **sphincter** is an opening that has a thick circle of muscle around it. During swallowing the sphincter relaxes to allow food to enter the stomach. You will recall that the esophagus joins the stomach just below the diaphragm. Study the structure of the walls of the esophagus as outlined on page 307 of your text. Note that the **cardiac sphincter** prevents regurgitation of food from the stomach to the esophagus.

Exercise 1

TRUE or FALSE. Circle your choice.

T F 1. The amoeba possesses a complex digestive system.

T F 2. An incomplete digestive system in animals involves one opening for the intake of food as well for the elimination of waste.

T F 3. In many multicellular animals, digestion occurs outside the body cells but inside the digestive tract.

T F 4. The primary function of a digestive system is to reduce large food molecules to their respective end products which are small enough to pass through plasma membranes.

T F 5. "A tube that sits inside another tube". This statement is accurate with respect to the digestive system of man.

T F 6. The mouth and the anus represent the anterior and posterior ends of the digestive system.

T F 7. The liver, gallbladder and pancreas represent the main regions of the digestive system in man.

T F 8. The tongue and its muscles form the side walls of the mouth cavity.

T F 9. Accessory organs of the digestive system located in the mouth are the salivary glands.

T F 10. The section of the digestive tract that serves as a passageway for food as well as a passageway for air is the pharynx.

T F 11. The glottis is a section of the food passage.

T F 12. Food is transported by way of the esophagus from the stomach to the small intestine.

13. What is the main function of the esophagus?

____

____

14. Which of the organisms mentioned in Lesson 3 possesses a digestive tract with a distinct foregut, midgut and hindgut?

____

15. When each of the following foods enters the human digestive system, each undergoes digestion. Name the end product in each case:

Carbohydrates - ______________________________

Proteins - ______________________________

Fats - ______________________________

16. List the three pairs of salivary glands located in the human body:

(a) ______________________________

(b) ______________________________

(c) ______________________________

17. List the two sphincters that regulate the entry and exit of food into and out of the stomach.

(a) ______________________________

(b) ______________________________

Please check your answers with those given on page 15.

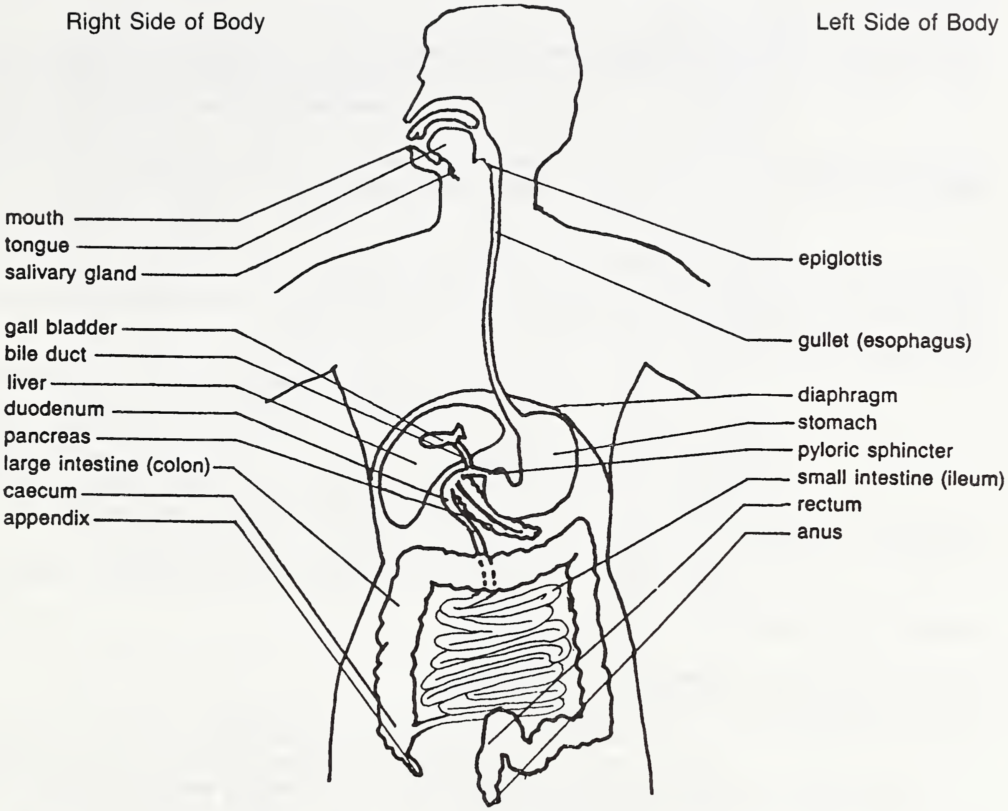


Figure 6: The Digestive System in Human Beings

The Stomach

The human stomach appears as a J-shaped sac lying in the upper left region of the abdominal cavity, just below the diaphragm, and is partly covered by the liver. The upper portion of the stomach is actually a continuation of the esophagus while the lower portion empties into the duodenum, the first part of the small intestine. The larger part of the stomach lies to the left of the median line (your right facing the page). In actual fact, the position of the stomach is not rigidly fixed. Each time the individual breathes in (inspiration) the stomach is pressed downward. As the individual breathes out (expiration) the stomach is pushed upward. For this reason, if a very heavy meal had been consumed and the stomach was fully distended, each inspiration would press the diaphragm down onto the stomach making it uncomfortable or difficult to breathe. Please refer to page 310 in your textbook for details on the muscle layers of the stomach.

When the stomach is empty, the lining of the stomach lies in large folds that can be seen with the unaided eye. These folds are called rugae (Roo-gi). When food is ingested the stomach fills and distends, the rugae smooth out and disappear. At the bottom of the rugae are the gastric pits or glands containing three types of secretory cells. These three types include the **zymogenic** (or chief cells) secreting the main gastric enzyme - pepsinogen; the **parietal** cells secreting hydrochloric acid and the **mucous cells** secreting mucus.

Please study the secretions of the stomach in lesson 5 of this course and also in your textbook on pages 310 and 311.

A. Features of the Stomach

The human stomach is divided into three basic areas. The end of the stomach that connects with the esophagus is the **cardiac end**. The other end of the stomach that connects with the small intestine is the **pyloric end**. Both points of connection are openings guarded by sphincters. The cardiac sphincter guards the opening of the esophagus to the stomach. Once food enters the stomach the sphincter prevents regurgitation to the esophagus. The pyloric sphincter guards the opening from the lower part of the stomach to the small intestine. Once food leaves the stomach and enters the small intestine the pyloric sphincter prevents regurgitation to the stomach.

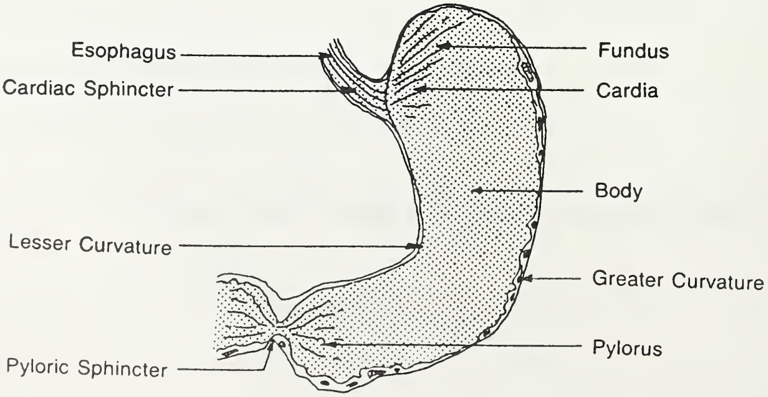


Figure 7: Divisions and Curvatures of the Stomach

Located near the cardiac end of the stomach is the **fundus**. The fundus is the enlarged portion to the left and a little above the point where the esophagus joins the stomach. The middle or central portion of the stomach is the **body**. NOTE: I am using the terms right and left here to indicate the sides of the stomach as it lies in the body, hence, the body's right and left, not the reader's/viewer's.

The pylorus is the lower end of the stomach. Generally speaking the right upper border of the stomach is known as the **lesser curvature**, while the lower left border is the **greater curvature**.

Functionally, the stomach serves as a reservoir, which stores food temporarily. As indicated earlier, the stomach secretes important digestive juices to chemically modify (digest) foods it contains. By alternate contraction and relaxation of its muscular walls, the stomach churns its contents, breaking food into smaller and smaller particles and at the same time mixing the food with gastric juice.

Exercise 2

1. Match the term in the left-hand column with the appropriate definition or explanation in the right-hand column.

______	secretory cells	A.	large folds of mucosa seen in the stomach when empty
______	sphincter	B.	an opening that has a thick band of muscles around it
______	rugae	C.	zymogenic, parietal and mucous glands
______	greater curvature	D.	enlarged portion near the cardiac end of the stomach
______	body	E.	lower left border of the stomach
______	fundus	F.	middle portion of the stomach

Complete the following statements.

2. The upper portion of the stomach is actually a continuation of the ____________________ .

3. At the bottom of the __________________ located in the stomach are the gastric pits or glands.

4. The regurgitation of food from the stomach to the esophagus is controlled by the ____________ ____________.

5. Functionally, the stomach serves as a reservoir for storing ______________ .

6. The right upper border of the stomach is known as the ______________ curvature.

7. Identify the structures labelled A to W in the illustration.

A. ______________________________

B. ______________________________

C. ______________________________

D. ______________________________

E. ______________________________

F. ______________________________

G. ______________________________

H. ______________________________

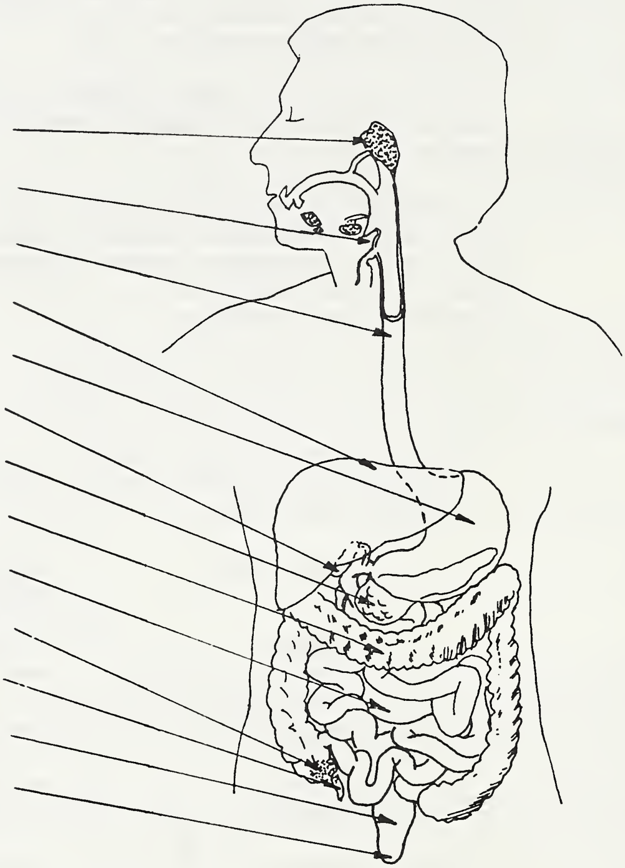
I. ______________________________

J. ______________________________

K. ______________________________

L. ______________________________

M. ______________________________



The Digestive System

Label the structures indicated by lines in the above drawing. Here is a list.

epiglottis
esophagus (gullet)
pancreas
stomach
salivary gland
rectum
small intestine

gall bladder
liver
large intestine
caecum
appendix
anus

Please check your answers with those given on page 16.

The Small Intestine

When food leaves the stomach it enters the **small intestine** by way of the pyloric valve or sphincter. This section of the digestive system is the most important of all the digestive organs. The small intestine averages about 6.35 metres in length. The actual length, however, may vary from 5 metres to 7 metres. A significant portion of the abdominal cavity is occupied by the coiled loops of this organ. The loops, however, are not totally unorganized. The loops are attached to the rear wall of the abdominal cavity by a thin membrane - the mesentery. Besides serving as attachment, the mesentery also serves as support for the intestine, preventing the loops from becoming entangled.

The small intestine begins at the pyloric sphincter and terminates at the caecum (the first section of the large intestine). The upper 25 cm of the small intestine is called the **duodenum** (doo-uh-dee-num). The next part of the small intestine is called the jejunum (ji-joo-num) and the rest or lowest portion is the **ileum**. Embedded in the mucous lining of the small intestine are numerous tiny **intestinal glands** which secrete intestinal juice containing digestive enzymes.

Functionally, the small intestine completes the digestion of food, absorbs the digested food so it can enter the bloodstream and moves the indigestible portions of food on to the next part of the digestive system - the **large intestine** or **colon**.

The Large Intestine

The colon (large intestine) of human beings functions primarily in absorption of water, the manufacturing of certain vitamins, collection of solid wastes (feces) and expulsion of feces from the body. The large intestine extends from the **ileum** to the **anus** and measures about 1.5 metres in length. It consists of the caecum, appendix, colon, rectum and anal canal. The colon is divided into four principal regions; the ascending colon, transverse colon, descending colon and sigmoid colon. (The term ''pelvic'' used in Figure 13.13 on page 318 of the text is not correct.) The ileum of the small intestine connects to the first part of the large intestine, called the **ascending colon**. The ascending colon rises up the right side of the abdominal cavity. At the point where the ileum opens into the large intestine, a fold of mucous membrane - the **ileocaecal valve** forms a sphincter for controlling this opening. The sphincter controls the rate at which materials pass from the **small intestine** (ileum) to the **large intestine**. Hanging below the ileocecal valve is the **caecum**, the first part of the large intestine. Attached to the caecum is a coiled worm-like hollow tube - the **appendix**. Food and bacteria sometimes get stuck in the appendix causing an infection known as appendicitis. If the infected appendix ruptures, bacteria spill into the abdominal cavity. These bacteria may cause a more serious infection known as **peritonitis**. I would like to mention here that the ascending colon and appendix are situated on the right side of the body.

The upper end of the ascending colon, lying just below the liver, turns and continues toward the left across the body. This part is the **transverse colon**. From a position near the spleen, the large intestine extends downward as the **descending colon**. The descending colon then connects to an S-shaped part of the colon, the sigmoid colon, which in turn is connected to the last part of the digestive system - the **rectum**. The rectum represents the final 20 cm of the digestive system. The last 2.5 cm of the rectum forms the **anal canal**. The mucous lining of the anal canal is arranged in vertical folds called **rectal columns**. Each rectal column is supplied with an **artery** and a **vein**. It is the **veins** that sometimes enlarge into **piles** or **painful hemorrhoids**.

Refer to the diagram on page 319 of your text for a review of the structures of the large intestine.

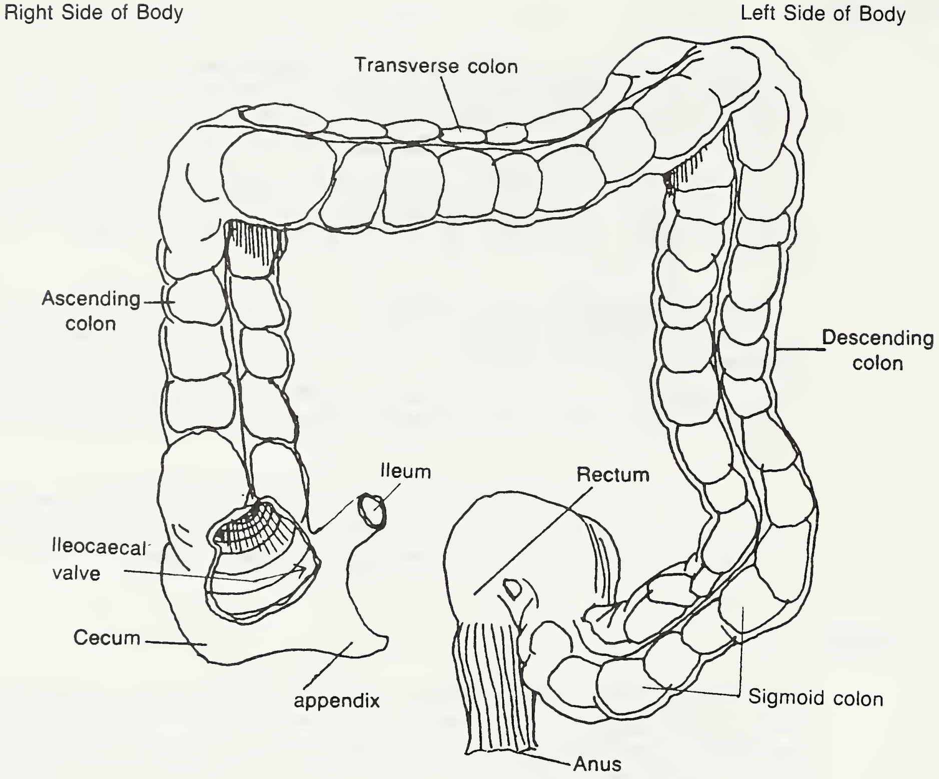


Figure 8: Structure of the Large Intestine

Accessory Digestive Organs

There are three structures within the abdominal cavity, but outside the digestive system, which are of great significance. These organs are the **liver, gallbladder** and the **pancreas**.

The Liver

This organ is located in the right upper part of the abdominal cavity. The largest gland in the body, the liver, weighs about 1.4 kg in the average adult. Lying just below the diaphragm in the body cavity, it partly overlaps the stomach. Structurally, two distinct lobes can be seen, the right and left.

As an organ, the liver receives a double supply of blood. From the hepatic artery it obtains oxygenated blood and from the hepatic portal vein it receives deoxygenated blood, laden with nutrients from the small intestine.

A major digestive function of the liver is the production of **bile**. When food is present in the small intestine, bile flows in and helps emulsify fats. This process causes large blobs of fat to be physically broken down into small droplets. These droplets are easily digested by special enzymes. When the small intestine is empty, the bile is stored and concentrated in the **gallbladder**. The liver performs a great many other vital functions, so many in fact, that we couldn't live without it.

The Gall Bladder

The gall bladder is the reservoir for bile. It is located on the underside of the liver. When filled with bile it becomes pearshaped. As food enters the duodenum (fats for example) the gall bladder contracts, squirting its contents into the duodenum. Scientific studies have shown that up to 450 mL of bile may be produced per day in some individuals.

The Pancreas

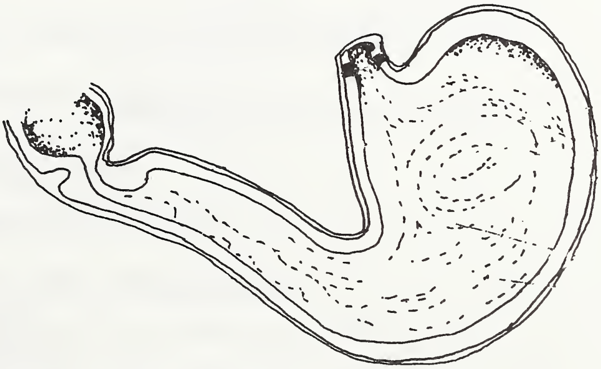
This leaf-shaped or pear-shaped gland (organ), closely associated with the digestive tract, measures 15 cm to 20 cm. The pancreas lies close to the stomach and is actually attached to the curve of the duodenum.

Functionally, the pancreas plays a significant role in digestion. This role will be studied in more detail in Lesson 5. Also it produces two important hormones, glucagon and insulin, which regulate blood sugar levels.

Exercise 3

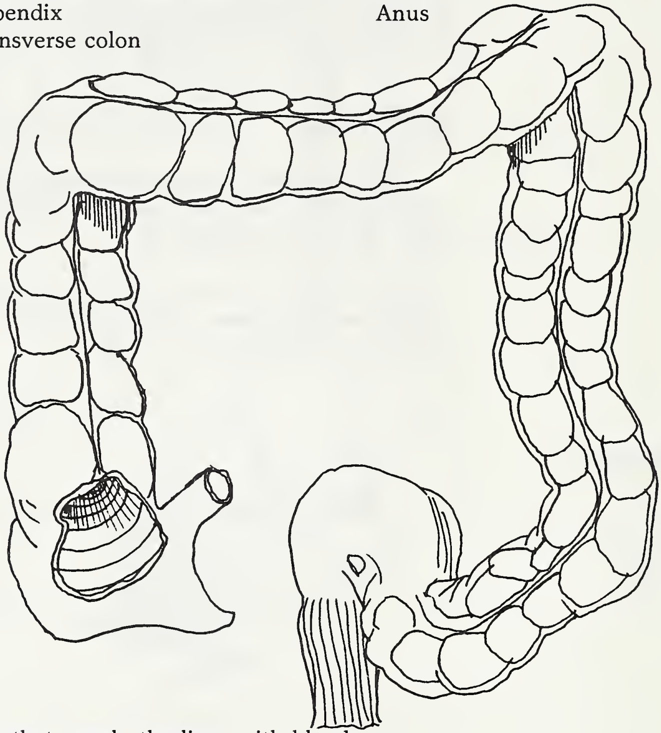
1. Label the drawing of the divisions and curvatures of the stomach as indicated.

Label:
Body
Fundus
Pyloric Sphincter
Cardia
Pylorus
Lesser Curvature
Greater Curvature
Cardiac Sphincter
Esophagus



2. Label the drawing of the large intestine as indicated.

Label:		
	Ascending colon	Descending colon
	Caecum	Rectum
	Appendix	Anus
	Transverse colon	



3. List the two vessels that supply the liver with blood.

(a) ______________________________

(b) ______________________________

4. Describe the location of the gallbladder.

____

____

____

____

5. Name the organ or gland that produces insulin in the human body.

____

____

Please check your answers with those given on pages 17 - 18.

ANSWERS TO SELF CORRECTING EXERCISES

Exercise 1.

True and False Questions

1. **False.**

2. **True.**

3. **True.**

4. **True.**

5. **True.**

6. **True.**

7. **False.**

8. **False.**

9. **True**

10. **True**

11. **False.**

12. **False.**

13. **It secretes mucous and transports food to the stomach.**

14. **The grasshopper (arthropods)**

15. Carbohydrates - **glucose**
    Proteins - **amino acids**
    Fats - **fatty acids and glycerol**

16. List the three pairs of salivary glands.
    (a) **parotid**
    (b) **submaxillary**
    (c) **sublingual**

17. List the two sphincters that regulate the entry of food into and out of the stomach.

    (a) **cardiac sphincter**

    (b) **pyloric sphincter**

ANSWERS TO SELF CORRECTING EXERCISES

Exercise 2

1. Match the term in the left-hand column with the appropriate definition or explanation in the right-hand column.

C	secretory cells	A.	large folds of mucosa seen in the stomach when empty
B	sphincter	B.	an opening that has a thick band of muscles around it
A	rugae	C.	zymogenic, parietal and mucous glands
E	greater curvature	D.	enlarged portion near the cardiac end of the stomach
F	body	E.	lower left border of the stomach
D	fundus	F.	middle portion of the stomach

Complete the following statements.

2. The upper portion of the stomach is actually a continuation of the **esophagus**.

3. At the bottom of the **rugae** located in the stomach are the gastric pits or glands.

4. The regurgitation of food from the stomach to the esophagus is controlled by the **cardiac sphincter**.

5. Functionally, the stomach serves as a reservoir for storing **food**.

6. The right upper border of the stomach is known as the **lesser** curvature.

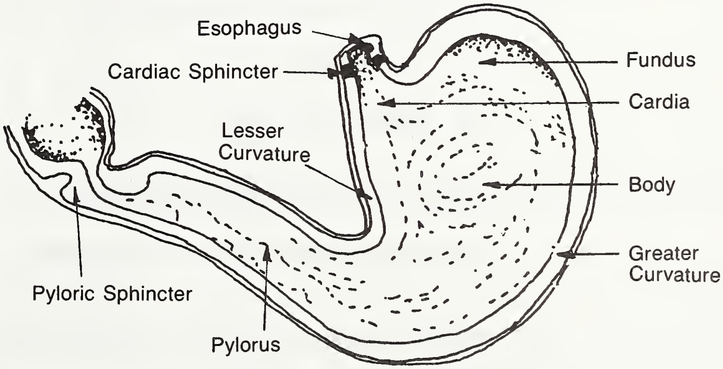
ANSWERS TO SELF CORRECTING EXERCISES

7. Identify the structures labelled A to W in the illustration.

A. **salivary gland**
B. **epiglottis**
C. **esophagus**
D. **liver**
E. **stomach**
F. **gall bladder**
G. **pancreas**
H. **large intestine**
I. **small intestine**
J. **caecum**
K. **appendix**
L. **rectum**
M. **anus**

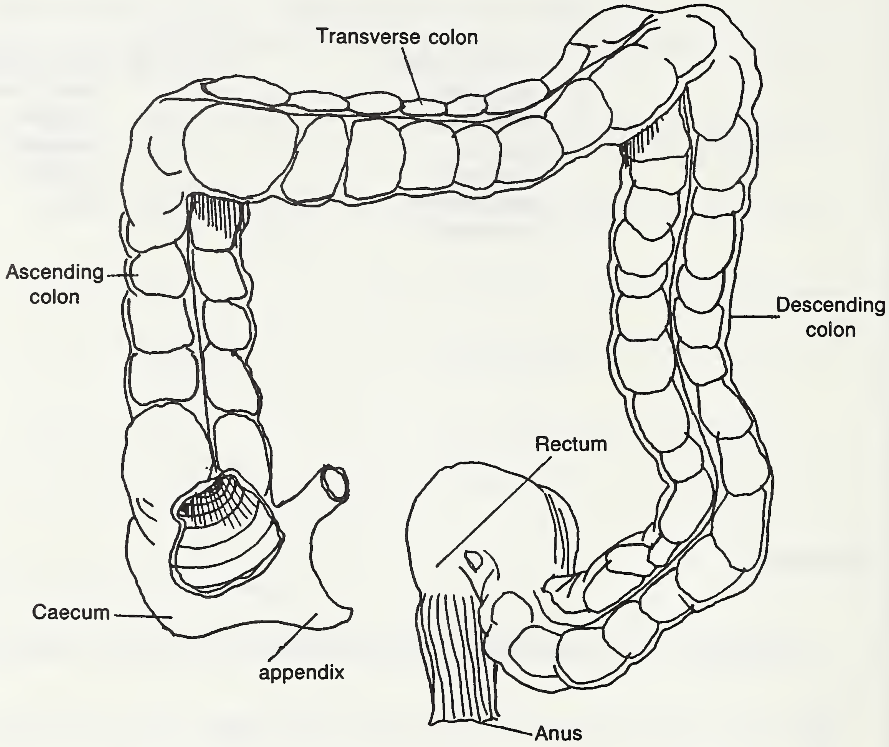
Exercise 3

1.



ANSWERS TO SELF CORRECTING EXERCISES

2.



3. List the two vessels that supply the liver with blood.

   (a) **hepatic artery**

   (b) **hepatic portal vein**

4. Describe the location of the gallbladder.

   It is located on the underside of the liver.

5. Name the organ or gland that produces insulin in the human body.

   the pancreas

EXERCISES TO BE SENT IN FOR CORRECTION

Select the best answer to each question and write the letter of your choice in the blank provided.

______ 1. When the stomach is empty, the gastric mucosa forms many wrinkles or folds. What are these features called?

(a) villi
(b) pylorus
(c) body
(d) rugae

______ 2. Which of the following is **not** a region of the large intestine?

(a) colon
(b) rectum
(c) anal canal
(d) duodenum

______ 3. The part of the alimentary canal in which a digestive juice is **not** secreted is the

(a) mouth.
(b) esophagus.
(c) stomach.
(d) small intestine.

______ 4. Which of the following is the **middle** part of the small intestine?

(a) duodenum
(b) ileum
(c) caecum
(d) jejunum

______ 5. What part of the intestine constitutes the pouch-like structure into which the ileum empties its contents?

(a) caecum
(b) rectum
(c) anus
(d) esophagus

______ 6. To which system does the esophagus belong?

(a) nervous
(b) digestive
(c) respiratory
(d) excretory

______ 7. Which of the following animals lacks the "tube-within-a-tube" organization of the digestive system?

(a) ascaris
(b) human
(c) amoeba
(d) grasshopper

______ 8. Which of the following is **not** considered an accessory organ of the digestive system?

(a) the gall bladder
(b) the liver
(c) the pancreas
(d) the appendix

______ 9. Which of the following is regarded as the reservoir for bile?

(a) the gall bladder
(b) the liver
(c) the pancreas
(d) the ileum

10. List the two major blood vessels supplying the liver with blood.

(a) ______________________________

(b) ______________________________

11. At what point along the digestive system is bile from the gall bladder emptied?

____

____

12. What is the major **digestive function** of the liver?

____

____

13. On which side of your body is your appendix located?

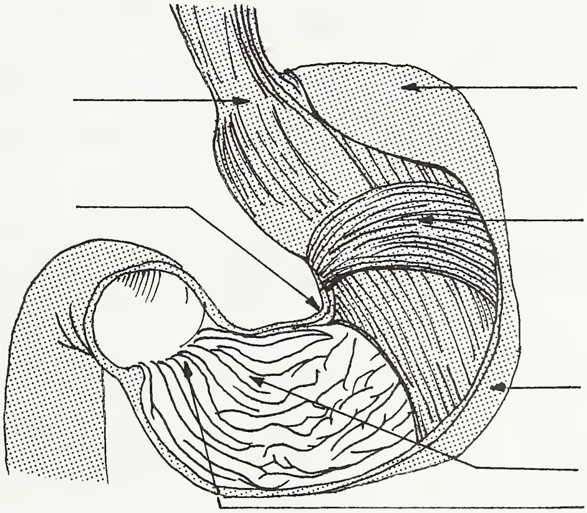
____

____

____

14. List the regions of the colon.

15. On the drawing provided (stomach) label the **pylorus, body, fundus, greater curvature, lesser curvature, cardiac sphincter, pyloric sphincter**.



16. How would you describe the shape of the stomach?

17. List the three pairs of salivary glands located in the human body.

(a) ______________________________

(b) ______________________________

(c) ______________________________

18. Define a sphincter.

____

____

____

TRUE or FALSE. Circle your choice.

T F 19. Accessory organs of the digestive system located in the mouth are the salivary glands.

T F 20. The section of the digestive tract that serves as a passageway for food as well as a passageway for air is the pharynx.

T F 21. The glottis is a section of the food passage.

T F 22. Food is transported by way of the esophagus from the stomach to the small intestine.

T F 23. The amoeba possesses a complex digestive system.

T F 24. An incomplete digestive system in animals involves one opening for the intake of food as well as for the elimination of waste.

T F 25. In many multicellular animals, digestion occurs outside the body cells but inside the digestive tract.

T F 26. The primary function of a digestive system is to reduce large food molecules to products which are small enough to pass through plasma membranes.

T F 27. "A tube that sits inside another tube." This statement is accurate as far as the digestive system of human beings goes.

T F 28. The mouth and the anus represent the anterior and posterior ends of the digestive system.

T F 29. The liver, gall bladder and pancreas represent the main regions of the digestive system in human beings.

T F 30. The tongue and its muscles form the side walls of the mouth cavity.

Please submit pages 19 - 22 for correction.

END OF LESSON 3

LESSON RECORD FORM

3230 Biology 30
Revised 03/89

FOR STUDENT USE ONLY

Date Lesson Submitted
____

Time Spent on Lesson
____

(If label is missing
or incorrect)

File Number
____

Lesson Number ________

FOR SCHOOL USE ONLY

Assigned Teacher: ________

Lesson Grading: ________

Additional Grading E/R/P Code: ________

Mark: ________

Graded by: ________

Assignment Code: ________

Date Lesson Received:
____

Lesson Recorded ________

Student's Questions and Comments

Apply Lesson Label Here

Name ______________________
Address ______________________
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____
Postal Code ______________________

Please verify that preprinted label is for correct course and lesson.

Teacher's Comments:

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ALBERTA CORRESPONDENCE SCHOOL

MAILING INSTRUCTIONS FOR CORRESPONDENCE LESSONS

1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

First Class

Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

OBJECTIVES

After completing Lesson 4, the student should be able to:

1. **Define** the term nutrients.
2. **Know** the six major classes of nutrients.
3. **Differentiate** between organic and inorganic compounds.
4. **Identify** carbohydrates, proteins, lipids (fats), nucleic acids, vitamins, minerals and water, and be able to give the importance of each.
5. **Know** the three major groups of carbohydrates: monosaccharides, disaccharides and polysaccharides.
6. **List** the three "simple sugars": glucose, fructose and galactose, and give dietary sources of each.
7. **Explain** how green plants produce glucose, starch and cellulose.
8. **Explain** how carbohydrates, fats (lipids), proteins, water, vitamins and minerals are used within the human body.
9. **Explain** how the blood glucose level is controlled by the pancreatic hormones - insulin and glucagon.
10. **List** some of the important dietary sources of carbohydrates, fats, proteins, vitamins and minerals.
11. **List** some of the diseases which may be related to the overconsumption of sugar.
12. **Identify** the general structural and functional differences between carbohydrates, lipids and proteins.
13. **Understand** why fats are the most concentrated type of fuel used by the body.
14. **Briefly explain** the structural differences between the three types of fatty acids.
15. **Understand** the various functions of cholesterol.
16. **Describe** the disease arteriosclerosis and explain how diet can either prevent or accelerate this disease.
17. **List** and describe the physiological functions of proteins.
18. **Differentiate** between non-essential and essential amino acids.
19. **Explain** how enzymes function to speed up reactions.
20. **Differentiate** between denaturation and deanimation.
21. **Identify** the structural and functional differences between DNA and RNA.
22. **Know** the basic structure of a nucleotide (a sugar, phosphate and nitrogenous base).

23. **Understand** the role of DNA and RNA.
24. **Understand** the double helix structure of DNA and how this is of importance in the replication of DNA and in RNA production.
25. **Explain** how water participates in chemical reactions - through either hydrolysis or dehydration synthesis.
26. **Explain** how excess carbohydrates, proteins and lipids (fats) are dealt with by the body.
27. **Differentiate** between fat-soluble and water-soluble vitamins.
28. **Understand** the importance of vitamins in the maintenance of metabolic processes within the body.
29. **Explain** the role of coenzymes.
30. **Be familiar** with the more common deficiency diseases which can occur with a lack of certain vitamins or minerals.
31. **Differentiate** between the processes: enrichment and fortification.
32. **Explain** the importance of fibre in the diet.
33. **Identify** simple or reducing sugars by using Benedict's solution.
34. **Identify** complex carbohydrates by using a dilute iodine solution.
35. **Identify** fats using the grease spot test and the Sudan IV dye test.
36. **Identify** proteins using Biuret reagent.

NUTRITION

Introduction

To stay healthy, our bodies require a constant flow of nutrients. These nutrients include both organic and inorganic substances. Organic substances are those compounds which contain carbon atoms while inorganic substances are those compounds which do not contain carbon atoms.

Organic compounds discussed in this lesson include; carbohydrates, fats, proteins, nucleic acids and vitamins. The inorganic compounds examined in this lesson include water and minerals. All of these compounds can be obtained by maintaining a well balanced diet. The foods we eat contain all of the required nutrients our body needs for growth, repair and energy.

In this lesson we will examine the structure of each compound and discuss its roles or functions within the body. Occasionally, structural diagrams of various compounds are given. These are included as general information and are not to be memorized or studied in detail. We will also examine the food sources of each nutrient and discuss the daily requirements and deficiency diseases which occur if some nutrients are lacking.

This lesson also includes laboratory investigations which deal with the identification of carbohydrates, fats and proteins. These identifications are made by using various chemical reagents or by examining certain physical properties of the compounds.

Nutrients

Food provides certain chemical substances needed for good health. **Nutrients** may be defined as those substances which are necessary for the functioning of the living organism. The body requires nutrients for:

1. material to build, repair or maintain body tissue.
2. the general maintenance and regulation of body systems.
3. fuel to provide energy to maintain all of the body functions.

The six major classes of nutrients are:

- Carbohydrates
- Fats
- Proteins
- Water
- Vitamins
- Minerals

Most foods contain all six classes of nutrients and usually water predominates. The three energy nutrients - carbohydrates, fats and proteins - are next in abundance. Last are the small, but significant, amounts of vitamins and minerals.

The human body contains all six classes of nutrients, in roughly similar proportions to those found in the foods we eat. A body weighing 68 kg contains about 40 kg of water, 14 kg of fat and 14 kg of proteins and carbohydrates. The remaining minerals, vitamins and "extras" make up only a fraction of a kilogram. By referring to the diagram on page 2 you can see that there is some truth to the old adage "you are what you eat".

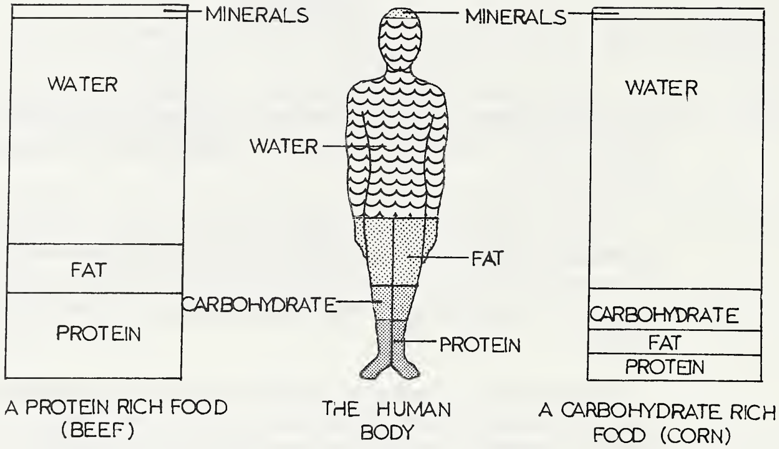


Figure 1: Composition of the human body and of two common foods. Vitamins are not shown because the quantities are too small to be seen on a graph of this size.

All of the nutrients are made up of atoms bonded together by energy. Of the six classes of nutrients, four contain carbon atoms, and are therefore called **organic** compounds. The organic (carbon-containing) nutrients include the carbohydrates, fats, proteins and vitamins. Being organic means that these classes of nutrients can be oxidized or burned (to carbon dioxide and water) and that energy will be released. The human body is capable of oxidizing carbohydrates, fats and proteins in such a way as to yield energy that the body can use. Vitamins cannot be used as an energy source; they instead participate in other important functions.

Those nutrient classes which lack carbon atoms are known as **inorganic** compounds. Water and minerals are used in many of the reactions within the body but they cannot be used as energy sources. Their roles will be discussed in further detail later in this lesson.

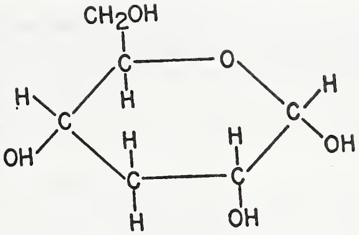
The following pages deal with each of the six nutrient classes (plus nucleic acids) in greater depth.

Carbohydrates

READ

Read the sections in your text dealing with carbohydrates (pp. 329-331)

Carbohydrates are a group of compounds which include sugars, starches and cellulose. These are all organic compounds, being made up of the elements carbon, hydrogen and oxygen. Glucose, a simple sugar with the molecular formula $C_6H_{12}O_6$, is an example of a carbohydrate. The diagram on page 3 is a structural drawing of one molecule of glucose. This diagram is only included for general information and is not to be memorized or studied in detail.

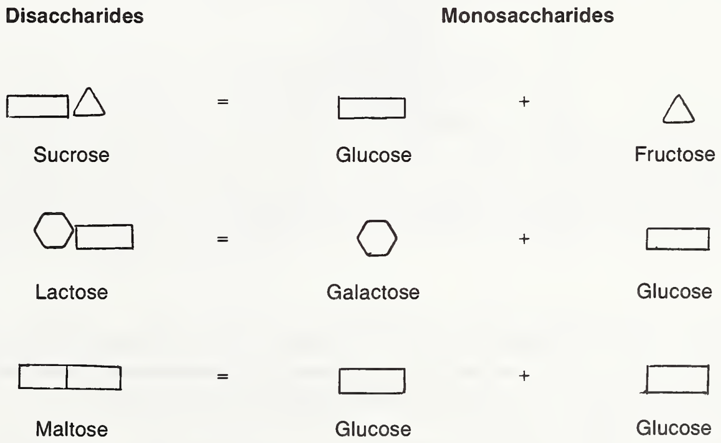


Glucose

Carbohydrates are classified into three main groups according to their complexity. These groups are the **monosaccharides, disaccharides** and **polysaccharides.**

Monosaccharides consist of a single carbohydrate unit and are often called ''simple sugars''. Examples of monosaccharides include glucose, fructose and galactose. Glucose (also known as dextrose, corn sugar and grape sugar) is found in milk, milk products, fruits and plant juices. Fructose is found in fruits, vegetables and honey. Glucose and fructose are the two most common sugars found in nature. Galactose is not found free in nature but it is always bonded to something else.

Simple sugars are commonly found bonded together in pairs. Pairs of simple sugars bonded together make up the group called disaccharides. The diagram below shows three common disaccharides and the monosaccharide components which go to make them up.



Ordinary white granulated table sugar which most people use in their coffee, tea or baking is actually the disaccharide **sucrose. Maltose** is found in germinating seeds, the product of enzyme activity on starch. Lactose is the only common sugar which is not found in plants. **Lactose** is produced in the mammary glands of mammals and is often called milk sugar. It remains in the intestines longer than other sugars and promotes the growth of colonies of intestinal bacteria.

All three disaccharides are easily digested, crystiline, sweet and easily soluble. Sugars added to food products for sweetness are usually disaccharides.

The last group of carbohydrates are the polysaccharides. Polysaccharides are large, complex molecules composed of many molecules of simple sugars. Examples of polysaccharides include; starch, glycogen and cellulose. Starch and cellulose are both products of the photosynthetic process of plants. Green plants are the only organisms capable of producing carbohydrates from carbon dioxide (CO_2) and water (H_2O).

Green plants use carbon dioxide, water and solar energy to produce glucose (see Figure 2A). Since glucose is water-soluble it is easily transported throughout the plant. Glucose cannot be stored because of its solubility, so the plant links the glucose units together to form starch (see Figure 2B). Starches are insoluble in water and therefore are used to make up the main energy reserves in plants.

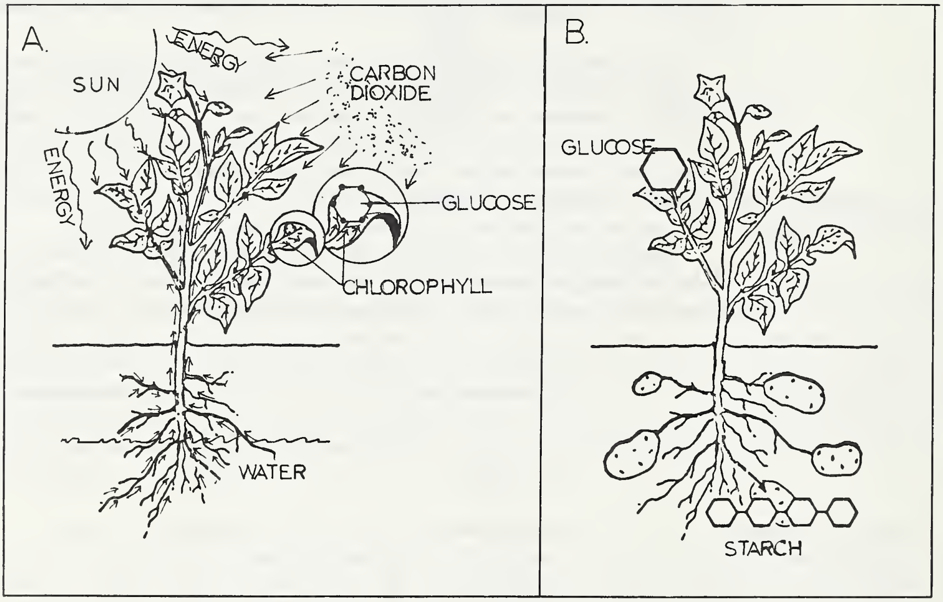


Figure 2: A. The green plant produces glucose using CO_2, H_2O and solar energy. B. Glucose is transported throughout the plant and glucose units are linked to each other to form starch.

Starches can be completely broken down to simple sugars by the human digestive tract. These are our most efficient source of fuel, being completely utilized without the production of toxic byproducts.

Cellulose is the other common polysaccharide which is produced by plants. Molecules of cellulose are complex, long-chained structures which may contain thousands of simple sugars linked together. The linkages between the simple sugars cannot be broken by the human digestive system. Cellulose is often referred to as plant fibre, being that indigestible material which passes through our intestinal tract unchanged. Cellulose is needed in our diet to keep up the muscle tone of the intestinal tract by providing bulk or roughage which has to be forcibly moved along.

Another important polysaccharide is **glycogen** an "animal starch". Excess glucose in the blood is removed by the liver and combined to build large, more complex molecules of glycogen.

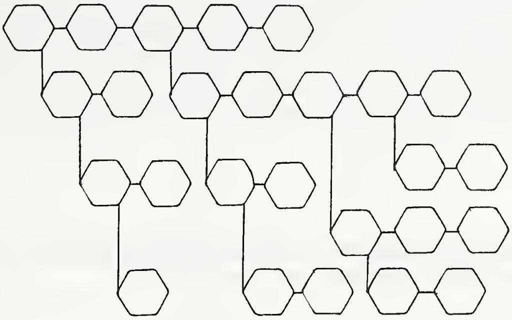


Figure 3: A molecule of glycogen. Notice that it is made entirely of glucose molecules.

Glycogen is the major form of carbohydrate storage in the human body. The liver and muscle cells are the major sites for the storage of glycogen, being readily available for conversion to glucose should the need for more energy present itself.

Carbohydrates in the Body

Carbohydrates are essential in a daily diet for the maintenance of proper health. Carbohydrates are the main source of fuel for the human body, normally supplying about two thirds of an individual's total energy needs. When insufficient amounts of carbohydrates are consumed, the body must break down fats and proteins to meet its energy demands. People trying to lose weight often cut back on their daily carbohydrate intake so that the body will break down their excess fat.

The human digestive system breaks down polysaccharides and disaccharides to simple sugars. These simple sugars are readily absorbed across the intestinal wall and pass into blood capillaries. Blood from the intestinal capillaries carries the simple sugars to the liver via the hepatic portal vein. The liver filters out glucose, slowly releasing it as required to the other cells of the body. Other simple sugars, like fructose and galactose, must be disassembled and rebuilt as molecules of glucose in the liver. This conversion is essential because our cells can only use glucose to power all of their reactions.

Glucose and Blood Sugar

Glucose is the main chemical energy source for the millions of cells in our body, each carrying out thousands of reactions at once. Without the chemical energy supplied by glucose, all cellular reactions would cease. The body will even break down its own proteins to maintain a sufficient amount of glucose in the blood.

The blood glucose level is carefully monitored by the endocrine cells of the pancreas. (The term endocrine is defined in the glossary at the back of your text.) After a meal, there is a flood of glucose into the bloodstream. This excess glucose stimulates certain endocrine cells of the pancreas to release the hormone, **insulin**. (The term hormone is also defined in the glossary of your text.) Insulin stimulates cells of the liver to take up glucose and convert it to glycogen or fat. If the blood glucose level falls too low, then other endocrine cells of the pancreas are stimulated. These cells produce the hormone **glucagon**. Glucagon stimulates the liver to convert stored glycogen to glucose, which is then released into the bloodstream. In this way the two hormones, insulin and glucagon, control the glucose level in the blood.

Read the sections in the text dealing with the endocrine glands, hormones and the pancreas. (pp. 396, 397 and 401-403)

Sources of Carbohydrates

Since green plants are the only organisms capable of producing carbohydrates from the raw materials water and carbon dioxide, it is not surprising that we derive the majority of our carbohydrates from plants. By eating virtually any and all parts of plants; the stems, leaves, roots, tubers, fruits, blossoms and seeds, we are able to meet our daily requirement of carbohydrates.

Different parts of the plant supply us with different carbohydrates; stems and leaves provide mostly cellulose (fibre); fruits and berries contain higher concentrations of sugars; roots, tubers and seeds contain higher concentrations of starch.

Seeds play an essential role in human diet, supplying over 50 percent of all human energy. The presence of worldwide staples such as peas, beans, wheat, rice, oats, millet, barley and corn can often mean the difference between starvation and survival. These staples provide the complex carbohydrates (starches) needed to meet human energy requirements.

Milk is another important contributor of carbohydrates in the diet. Milk contains generous amounts of the disaccharide lactose (milk sugar). The lactose in milk provides infants with the energy source needed for their growing bodies.

For thousands of years, our major sources of carbohydrates were the starches in plants and the lactose in milk. It has only been in the last 100 years that some simple carbohydrates have been purified to produce table sugar (sucrose). In the Western world, the intake of concentrated simple sugars makes up half of the total carbohydrate intake. Ordinary table sugar is often added as a sweetener to the foods we eat. Cookies, cakes, soda pop and candy all have a high sugar content. The replacement of complex carbohydrates by simple sugars in our diet is said to be ''unnatural''. Sugar overconsumption has been implicated in either causing or setting the stage for the following diseases: hypoglycemia, diabetes, artherosclerosis (hardening of the arteries), high blood pressure, hyperactivity, tooth decay and obesity.

Exercise 1

1. Complete each of the following statements by filling in the numbered blank on the right.

(a) Compounds containing carbon atoms are known as ____(1)____ compounds.

(b) All carbohydrates are made up of the three elements; ____(2)____, ____(3)____ and ____(4)____.

(c) Ordinary white granulated table sugar is actually the disaccharide ____(5)____ .

(d) Three examples of monosaccharides would be ____(6)____, ____(7)____ and ____(8)____.

(e) Starch, glycogen and cellulose are all examples of ____(9)____ .

(f) The disaccharide produced by the mammary glands of mammals is called ____(10)____.

(g) Green plants use ____(11)____, ____(12)____ and carbon dioxide to produce glucose.

(1) ______________________

any order { (2) ______________________
(3) ______________________
(4) ______________________ }

(5) ______________________

any order { (6) ______________________
(7) ______________________
(8) ______________________ }

(9) ______________________

(10) ______________________

any order { (11) ______________________
(12) ______________________ }

2. Match the following using the information given on pages 396, 397 and 401-405 of your text. Write the letter of the item described in the blank beside each statement. **Do not** use any letter more than once.

______ secrete their products into tubes or a chamber

______ causes a drop in the glucose level in the blood

______ only elicits a response from the target organ(s)

______ causes an increase in the glucose level of the blood

______ secrete their products directly into the bloodstream

______ can be converted to glucose by the liver to raise the blood glucose level

A. glycogen
B. thyroxin
C. exocrine glands
D. endocrine glands
E. glucagon
F. insulin
G. hormones
H. vitamins

3. List the six major classes of nutrients.

(a) ______________ (d) ______________

(b) ______________ (e) ______________

(c) ______________ (f) ______________

Please check your answers with those given on page 24.

Fats

READ

Read the sections in the text dealing with fats (pp. 331-333).

Fats are composed of the same three elements that are found in carbohydrates; carbon (C), hydrogen (H), and oxygen (O). Fat is, however, a more concentrated fuel because it contains more carbon and less oxygen than carbohydrates. A much higher percentage of a fat molecule can be burned (combined with oxygen) to produce energy. This is why there are 9 calories of energy in each gram of fat and only 4 calories in each gram of carbohydrate.

About 95% of the fats in our food and bodies are in the form of triglycerides - one molecule of glycerol combined with three molecules of fatty acids.

READ

Refer to the diagrams in your text dealing with the structure of fats and fatty acids (p. 332).

The human body can synthesize all of the required fatty acids from carbohydrate, fat and protein except one - **linoleic acid**. This fatty acid is considered to be an essential fatty acid, one which is required in the daily diet.

Fats serve several purposes in the diet. They enhance the palatability of meals, since many flavours and aromas are fat-soluble substances. Certain fats also function as carriers for the fat-soluble vitamins A, D, E and K.

The Body's Use of Fats

In the cell, triglycerides are broken down into glycerol and fatty acids. Two molecules of glycerol could then be combined to form one molecule of glucose. Glycerol can also be broken down to produce energy. Most of the energy derived from fat is the result of the breakdown of the large fatty acids. These cannot be converted to glucose so they are broken down by the processes of cellular respiration.

Excess fats present in the bloodstream can be removed by any cell in the body for use as an energy source or for storage. Most cells have a limited capacity for the storage of fats. Fat cells, however, can expand indefinitely for the storage of fats. In an adult the number of fat cells is fixed, so the major difference between a thin person and an obese person is the size of their fat cells.

Cholesterol

Cholesterol is essential to life. It is a major component of bile, assisting in the emulsification of fats. Cholesterol is also a major component of all cellular membranes and the fatty sheath which surrounds and insulates nerve fibres. It is also a precursor for certain sex hormones, such as **estrogens**.

Most of the cholesterol required by the body is manufactured by the liver. Between twenty and thirty percent is also obtained from the foods we eat. Cholesterol is a major constituent of the plaques that cause a narrowing of the arteries in the disease **arteriosclerosis**. This disease, also known as "hardening of the arteries", has been implicated as one of the major causes of heart disease. Cardiovascular disease (heart and circulatory disorders) is the leading cause of death in North America. This had led to a justified concern regarding the cholesterol levels in the blood.

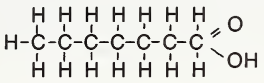
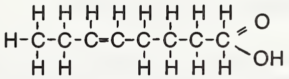
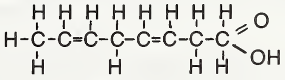
Type of Fatty Acid	Diagramatic Representation	Food Sources
Saturated Fatty Acids	 $H-C-C-C-C-C-C-C(=O)OH$	Butter, Whole Milk, Bacon and Fatty Meats
Monounsaturated Fatty Acids	 $H-C-C-C=C-C-C-C-C(=O)OH$	Olive oil
Polyunsaturated Fatty Acids	 $H-C-C=C-C-C=C-C-C(=O)OH$	Most vegetable oils and some fish (salmon, mackeral and herring)

Table 1: Types of fatty acids, their structural formulas and food sources

The cholesterol level in the blood is not constant. Research has shown that the blood cholesterol level may be elevated or reduced, depending upon the types of fatty acids present in the diet. Studies seem to indicate that a high dietary consumption of cholesterol and saturated fats may lead to an elevated blood cholesterol level. Polyunsaturated fats seem to have the opposite effect, reducing the blood cholesterol level in some people.

By lowering the total fat intake and reducing the intake of saturated fats we should be able to prevent, or at least slow down, the deposition of plaque associated with arteriosclerosis.

Proteins

READ

Read the sections of your text dealing with protein (pp. 333-336)

Protein is one of the basic structural components of every cell in the human body. More than half of the dry weight of every cell is protein. It comprises a major part of muscle tissue, connective tissue, cartilage, bone, skin, hair, mucous secretions, genetic material and cell membranes. Not only does protein make up the bulk of these structures but it also plays several important roles in the functioning of the human body.

Physiological Functions of Proteins

A. Growth and Maintenance

One of the functions of proteins in our diet is to supply amino acids for the construction of new proteins. These new proteins can be used for the production of new tissues or for the replacement of old worn-out structures. Nearly all of the cells in the body are constantly being replaced. Cells lining the intestine are replaced every 72 hours; red blood cells are constantly being replaced and our hair and nails are always growing. Proteins make up a major part of these structures.

B. Enzymes and Hormones

Enzymes are protein catalysts, increasing the rate of reactions. Enzymes are very specific, combining only certain substances to form one product. This specificity is thought to be due to the method by which enzymes work.

READ

Read pages 32 and 33 of your text for a review of enzyme structure and function.

There may be as many as 1000 different enzymes within a single cell, each catalyzing a different reaction.

Many hormones are also proteins. Hormones help to regulate overall body conditions, controlling general factors such as blood glucose level and metabolic rate.

C. Antibodies

Antibodies are proteins which are usually produced in response to the presence of ''foreign proteins'' in the body. These foreign proteins may be parts of a virus, bacterium or toxin. Antibodies act much like an enzyme, bonding to the foreign protein. Unlike enzymes, however, antibodies inactivate or destroy the foreign proteins.

D. Fluid balance

A cell must maintain a constant amount of fluid to remain alive - too much fluid and it bursts, too little and it ceases to function. Water can pass in and out of cell membranes but proteins cannot. Since these proteins attract water they help regulate the quantity of fluids within the compartments of the body.

E. Salt balance

Not only quantity but also the quality of the fluid within the cell is important. Certain transport proteins in the cellular membrane respond to minute changes in salt concentration by pumping substances into or out of the cell. Nerve and muscle cells depend on transport proteins to keep sodium ions concentrated outside the cell and potassium ions within.

F. Acid-base balance

Normal body processes produce acids and bases which must be transported by the blood to the excretory organs. Proteins in the blood act as **buffers**, removing hydrogen ions when there are too many and releasing them when there are too few. Proteins, in this way, help to maintain a constant pH of 7.2 (slightly alkaline). A constant pH is essential if normal metabolic processes are to take place.

Denaturation of Proteins

The amino acids in proteins are not arranged in simply a one-dimensional configuration like letters in a word. Instead, chains of amino acids are arranged in complex, three-dimensional shapes. This three-dimensional structure is often essential to the proper functioning of the protein molecule.

Certain physical and chemical agents are able to break certain bonds within the protein molecule, altering its three-dimensional structure. Heat, alcohol, acids and various heavy metal salts are all able to disrupt proteins. The process by which proteins lose their characteristic three-dimensional structure is known as **denaturation**.

There are times when the denaturation of proteins is encouraged. When administering a needle, a nurse first rubs alcohol on your skin to sterilize it. The alcohol penetrates the protein coat of any bacteria present, altering its structure and destroying the bacteria.

Deamination

Proteins are essential nutrients for a wide variety of processes, but it is possible to ingest more proteins than required. Excess proteins cannot be stored, but they can be used as fuel.

Once a protein has been reduced to its amino acids, the nitrogen-containing portion (amine group) must be removed. The process by which the amine group is removed from the amino acid is known as **deamination**. In the human body amino acids are deaminated in the liver, with the nitrogen portion being converted to urea. The urea is then transported to the kidneys and excreted.

Once the amine group is removed, the rest of the amino acid can be oxidized in the same manner as carbohydrates or fats. Some amino acids can also be broken down to produce glucose. This glucose can then be used to maintain a steady blood glucose level during times of reduced carbohydrate intake.

Nucleic Acids

Nucleic acids are a group of organic compounds which play extremely important roles in heredity and protein synthesis. Nucleic acids are not considered to be major nutrients for the human body. They are, however, important components of all cells.

There are two basic types of nucleic acids found within each cell, DNA (deoxyribonucleic acid) and RNA (ribonucleic acid). DNA is found exclusively within the nucleus of all cells. RNA can be found both within the nucleus and cytoplasm.

Within the nucleus, DNA and proteins combine to form chromosomes. A complete set of chromosomes provides a complete set of instructions for the development of a cell and all of its ancestors. In a normal cell, the genetic material exists as thread-like structures (chromatin) not easily distinguished from the rest of the nucleus. However, when a cell starts to divide, the chromosomes shorten and thicken, making them easier to identify.

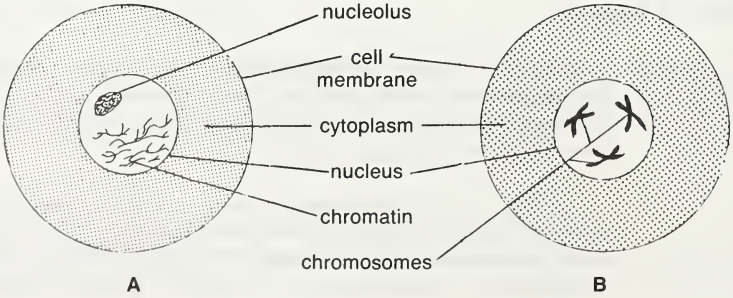


Figure 3: Showing (A) the normal cell with thread-like chromatin and (B) a cell preparing to undergo cell division with well defined chromosomes.

Structure of DNA

DNA is an extremely large, complex molecule composed of thousands of similar repeating units called **nucleotides**. In DNA each of these nucleotides is composed of three fundamental compounds; a monosaccharide called **deoxyribose,** a **phosphate** group and **one** of four **nitrogenous bases**. The four possible bases include **adenine, cytosine, guanine** and **thymine**. The four bases have the code letters A, G, C and T.

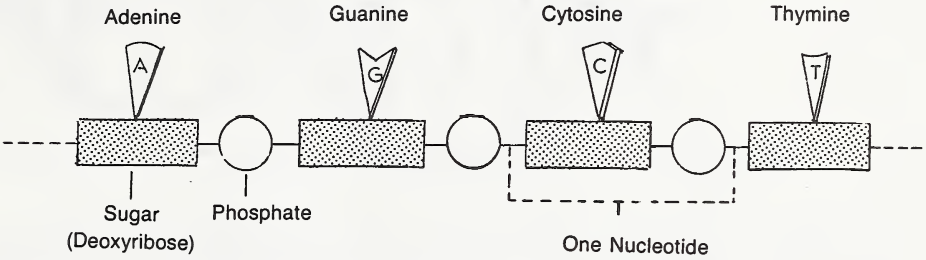
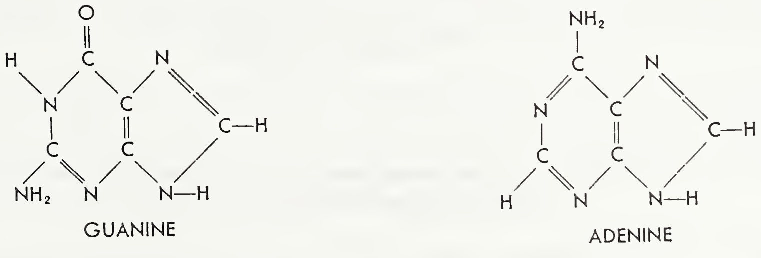


Figure 4: A small portion of a DNA molecule, showing the nucleotide units with different bases. (This is a simple diagramatic representation).

The nitrogenous bases found in nucleic acids can be divided into two major categories based on their three-dimensional structure. Those bases possessing a double-ring structure are called **purines** and those bases with only a single ring are called **pyrimidines**.

Purines



Pyrimidines

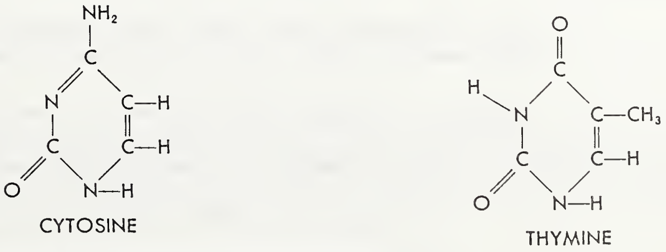


Figure 5: The structural formulas of the four nitrogenous bases in DNA.

Each chromosome within the nucleus consists of a double parallel chain of DNA. The DNA stands are coiled, forming a spiral or helix. Since there are two strands in each chromosome the structure is called a double helix.

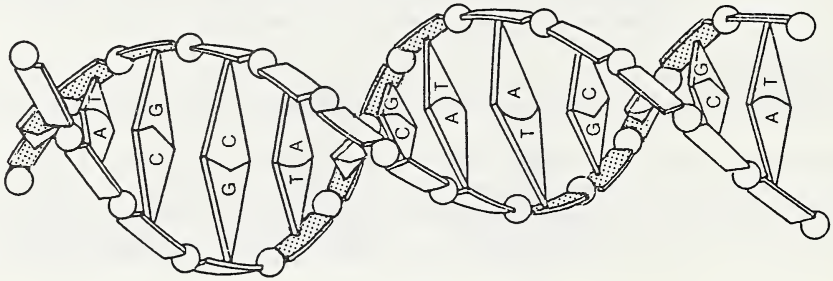


Figure 6: A very small portion of a DNA molecule, showing the double helix structure.

The nitrogenous bases of the nucleotides join to hold the two strands of DNA together. The bases always pair up in a definite way; adenine always joins with thymine and guanine always joins with cytosine (notice that a purine always joins a pyrimidine). The bases join this way because they have complementary surface shapes which fit together much like an enzyme and its substrate.

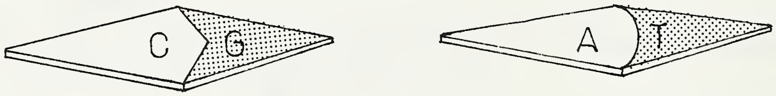


Figure 7: Purine-pyrimidine bonding of base pairs. Notice how the complementary surface shapes join together.

RNA Structure

RNA (ribonucleic acid) is a large, complex molecule composed of similar repeating units called nucleotides. RNA is, however, quite small when compared to DNA.

There are three major differences between the structures of RNA and DNA.

1. RNA is composed of a single strand of nucleotides.
2. The nucleotides in RNA contain the monosaccharide **ribose.**
3. RNA contains the pyrimidine **uracil**, instead of thymine.

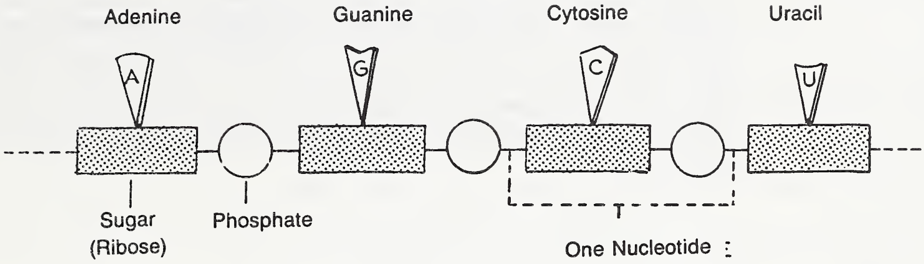


Figure 8: A diagramatic representation of a portion of a RNA molecule.

RNA is found within both the nucleus and cytoplasm of a cell. It plays a major role in the transfer of information from DNA molecules within the nucleus, to ribosomes in the cytoplasm. RNA transfers coded information from the DNA molecule to the ribosome for the production of proteins. RNA also plays a major role in the production of proteins.

Protein synthesis has been described in detail in Biology 20. If you would like further information please refer to a Biology 20 text.

The Role of DNA

All genetic information within a cell is contained in the DNA of the chromosomes. Sections of DNA along each chromosome correspond to units of heredity that are called **genes**. Each gene codes for the synthesis of specific proteins necessary for a specific trait or characteristic.

DNA is also self-replicating, being the only organic molecule which is able to reproduce itself. This self-replication allows for the transfer of genetic information to offspring. By transferring a complete set of genes to its offspring, an organism is able to ensure the continuance of specific inheritable characteristics. Children tend to look like their mother or father because they have inherited genes from both.

DNA replication and the concepts of heredity have already been discussed in Biology 20. For further information please refer to a Biology 20 text.

Digestion of Nucleic Acids

Nucleic acids are not one of the major nutrients required by the human body. Despite being large organic molecules, nucleic acids make up a relatively small portion of the foods we eat. This means that nucleic acids supply only a small portion of the nutrients needed by the body.

Nucleic acids are broken down by digestive enzymes secreted by the pancreas and intestinal glands. These digestive enzymes are called **nucleases**. Nuclease breaks down the long-chain nucleic acids into individual nucleotides. Other enzymes reduce the nucleotides to their basic components; a monosaccharide, a nitrogenous base and a phosphate group. These components can then be absorbed by the small intestine and distributed throughout the body via the bloodstream. The end-products of nucleic acid digestion can then be utilized by all cells.

Exercise 2

1. Complete each of the following statements by filling in the numbered blank on the right.

(a) A ____(1)____ is composed of one molecule of glycerol and three molecules of fatty acid.

(b) A major component of the plaque that narrows arteries is ____(2)____ .

(c) ____(3)____ proteins are usually of poorer quality, lacking most of the essential amino acids.

(d) Sections of DNA which correspond to units of heredity are called ____(4)____ .

(e) ____(5)____ is the only organic molecule which is self-replicating.

(f) Over half of the dry weight of every cell in the human body is ____(6)____ .

(g) The disease which causes the narrowing or blockage of the arteries is called ____(7)____ .

(h) The major difference between a thin and an obese person is the ____(8)____ of their fat cells.

(i) ____(9)____ are protein catalysts, increasing the rate of reactions within the body.

(j) There are only ____(10)____ different kinds of amino acids in the human body.

(1) ____________________

(2) ____________________

(3) ____________________

(4) ____________________

(5) ____________________

(6) ____________________

(7) ____________________

(8) ____________________

(9) ____________________

(10) ____________________

2. Indicate whether the following statements are **True** or **False** by circling the correct letter at the beginning of each statement.

T F (a) Salmon, mackeral and herring are high dietary sources of saturated fatty acids.

T F (b) Proteins help regulate the quantity of water within cells.

T F (c) Two molecules of glycerol may combine to form one molecule of glucose.

T F (d) The process by which proteins lose their characteristic three-dimensional structure is known as respiration.

T F (e) DNA possesses four possible nitrogenous bases; adenine, guanine, cytosine and uracil.

T F (f) Research has shown that the consumption of saturated fatty acids tends to increase the blood cholesterol level.

T F (g) Fat is a more concentrated fuel than carbohydrate because it contains more oxygen atoms.

3. Match the following by writing the letter of the item described in the blank beside each statement. **Do not** use any letter more than once.

______ a nitrogenous base found only in RNA

______ genetic material with a thread-like structure

______ inactivate or destroy foreign particles

______ precursor for the hormone estrogen

______ specific protein catalysts which speed up reactions

______ a nitrogenous base found only in DNA

______ the basic repeating unit of nucleic acids

______ help regulate overall body conditions

A. nucleotide
B. thymine
C. uracil
D. cytosine
E. hormones
F. chromatin
G. chromosomes
H. enzymes
I. antibodies
J. cholesterol
K. deoxyribose

Please check your answers with those given on page 25.

Water

READ

Read the section of your text dealing with water. (p. 336)

Water is an integral part of the human body, both physically and chemically. Water is an inorganic compound, composed of two hydrogen atoms and one oxygen atom (H_2O). Our bodies are mostly water, some 65% of the total body weight. Each individual cell in the body must be bathed in water to keep it alive. This water brings the cell all essential substances and carries away the waste products of cellular reactions.

Water also participates in many of the chemical reactions which occur in the human body, instead of being just the medium in which they take place. The chemical digestion of food within the digestive tract has water as an active ingredient in the decomposition of materials. The breakdown of the disaccharide maltose is an example of the role of water in the digestive process.

Water, in the presence of the digestive enzyme maltase, assists in splitting the disaccharide maltose into two glucose units. Water participates by being split, with a hydrogen atom joining one glucose, and oxygen and hydrogen joining the other. By this action, the two glucose units are made complete. This process of splitting a molecule by adding water is known as **hydrolysis**.

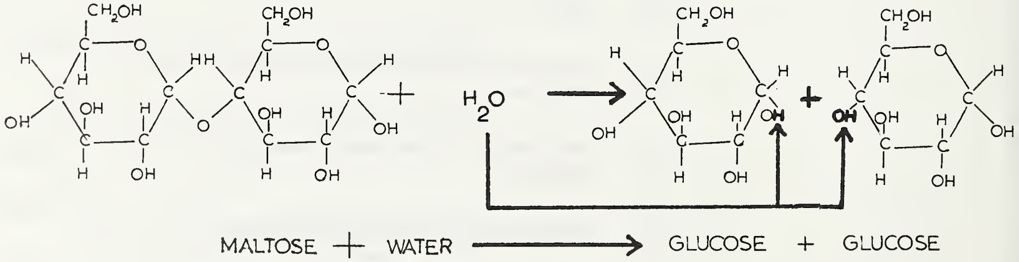


Figure 9: Maltose is broken down into two molecules of glucose by hydrolysis. Atoms from water are added to the broken bonds.

The opposite reaction can also occur. Two molecules can be united to form a larger, more complex molecule with the removal of water. Proteins and other macromolecules are built by combining smaller molecules. This process is called **dehydration synthesis** because the new molecule is made by removing a molecule of water.

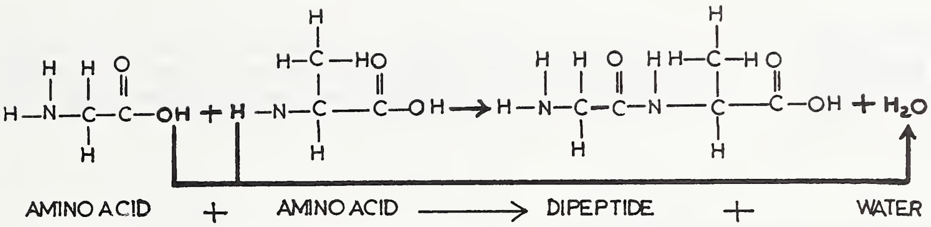


Figure 10: The formation of a dipeptide by dehydration synthesis. Note that the removal of one molecule of water provides a bonding point for the two amino acids.

Vitamins

Read the sections of your text dealing with vitamins (pp. 337-341).

Vitamins are a group of organic compounds that are essential for the healthy functioning of the body. These compounds are only required in small quantities. A well balanced diet ensures that the body receives all of the required vitamins it needs.

More than thirty compounds are known to possess the properties which identify them as being vitamins. None of these compounds have any food value, but they all play important roles assisting various metabolic processes within the cell.

Vitamins do not enter directly into cellular reactions. Their presence is, however, necessary if a reaction is to take place. Some vitamins participate in reactions by becoming part of **coenzyme**. A coenzyme is a molecule that can combine with an inactive protein to form an active enzyme. The following diagrams demonstrate the importance of coenzymes.

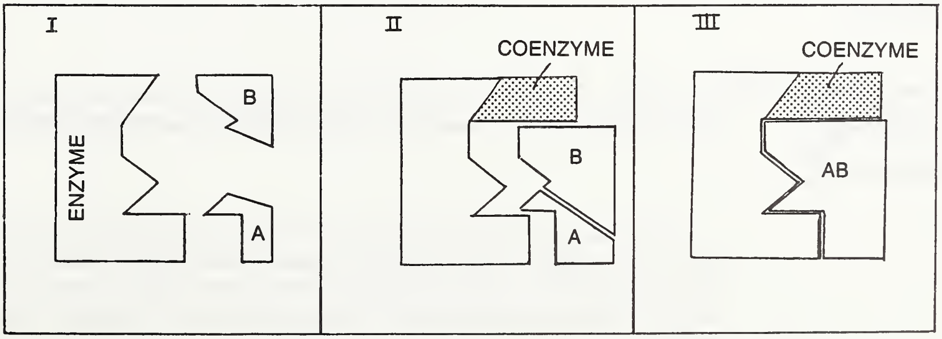


Figure 11: (I) Without the coenzyme, compounds A and B do not respond to the enzyme. (II) With the coenzyme in place, compounds A and B are attracted to the active site on the enzyme. (III) Compounds A and B react, forming the product AB. Notice that the enzyme does not take part in the reaction and remains unchanged.

READ

All cells require **all** vitamins. If a vitamin deficiency exists, some metabolic processes in **all** cells will be impaired. For more information regarding the deficiency symptoms, due to a lack of specific vitamins, **please refer to the table on pages 340 and 341 of your text.**

Enrichment and Fortification of Food

Most people prefer refined white bread to whole wheat bread. Refined white flour lacks iron, thiamin, riboflavin and niacin. These nutrients, originally present in cereal grains, are lost during the processing of flour. To prevent deficiency diseases due to a lack of these nutrients, iron, thiamin, riboflavin and niacin are added to the flour. The process of replacing lost nutrients is called enrichment. Enriched white bread possesses the original levels of iron, thiamin, riboflavin and niacin. This makes refined white bread almost as nutritious as whole wheat bread, lacking only the fibre content.

Many of the foods we eat are said to be fortified with vitamins or minerals. Fortification involves the addition of any nutrient (even one that was not originally present) to a food substance. Fortified foods may also have nutrients added in amounts well above natural limits. In North America, milk is fortified with vitamins A and D and most fruit drinks are fortified with vitamin C.

Most vitamins and minerals are added to our food for nutritional purposes. Adding vitamins and minerals to various refined and processed foods helps replace lost nutrients and prevents the development of deficiency diseases. The enrichment and fortification of foods, on a national scale, helps to improve the general health of the entire population.

Vitamin C is often an exception to this rule. It is often added to processed foods as an antioxident to preserve color and quality.

Minerals

READ

Read the sections of your text dealing with minerals. (pp. 339-342).

Minerals are inorganic substances which make up only a very small percentage of the total body weight. A 60 kg person contains about 2.5 kg of minerals. This 2.5 kg is made up of at least 20 different minerals, all of which play some essential role(s) within the human body. The following table lists the 20 minerals known to be of some importance to the human body.

MINERAL	CHEMICAL SYMBOL	MINERAL	CHEMICAL SYMBOL
Calcium	Ca	Zinc	Zn
Phosphorus	P	Manganese	Mn
Potassium	K	Cobalt	Co
Sulfur	S	Chromium	Cr
Sodium	Na	Selinium	Se
Chloride	Cl	Molybdenum	Mo
Magnesium	Mg	Fluorine	F
Iron	Fe	Tin	Sn
Iodine	I	Silicon	Si
Copper	Cu	Vanadium	V

Table 2: A list of the essential minerals in the human body

Minerals play many essential roles within the human body. Calcium and phosphorus are important structural components of bones and teeth. Magnesium is also present in bone and is necessary for nerve and muscle activity. Magnesium and phosphorus are also essential parts of a large number of enzymes. Chlorine, potassium and sodium all help preserve the acid-base balance of the body's fluids. Chlorine is also necessary for the formation of hydrochloric acid, a component of gastric juice. Proteins contain large amounts of sulfur. Sulfur bonds adjacent protein molecules together to give greater strength to the tissues formed (hair, nails and skin).

READ

These are just a few of the functions that are attributed to some of the minerals. **All** minerals play essential roles within the body. The major roles of minerals are listed on page 342 of your text. Please review this page and the table on page 341.

Fibre in the Diet

READ

Read the section of your text dealing with fibre (pp. 342 and 343). Then go on to Exercise 3.

Exercise 3

1. Match the following by writing the letter of the item described in the blank beside each statement. **Do not** use any letter more than once.

_______ the process of splitting a molecule by adding water

_______ the process of building more complex molecules by removing water

_______ a structural component of bones and teeth

_______ a molecule that combines with an inactive protein to form an active enzyme

_______ necessary for the formation of a component of gastric juice

_______ the replacement of lost nutrients to original levels

_______ the addition of any nutrient, in any amount, to a food substance

_______ aids in the retention of water by the large intestine

_______ strengthens tissues by bonding adjacent proteins together

A. calcium

B. emulsification

C. enrichment

D. chlorine

E. dehydration synthesis

F. sulfur

G. fibre

H. cholesterol

I. fortification

J. hydrolysis

K. coenzyme

L. vitamin C

2. Complete each of the following statements by filling in the numbered blank on the right.

(a) The ____(1)____ of water from the skin assists in cooling the body.

(b) ____(2)____ are organic molecules which have no food value.

(c) Water is an inorganic molecule, composed of ____(3)____ and ____(4)____ atoms.

(d) Toxic minerals which often contaminate the foods we eat are called ____(5)____ ____(5)____ (two words).

(e) The mineral, ____(6)____, is necessary for the formation of hemoglobin.

(f) ____(7)____ is added to many water supplies to strengthen teeth.

(g) Ascorbic acid is more commonly known as ____(8)____ .

(h) Vitamin K and some B vitamins are produced by ____(9)____ in the ____(10)____ ____(10)____ (two words).

(1) ____________________

(2) ____________________

(3) ____________________

(4) ____________________

(5) ____________________

(6) ____________________

(7) ____________________

(8) ____________________

(9) ____________________

(10) ____________________

3. Vitamins are divided into two major groups. List at least three examples for each of the following.

(a) Water-soluble vitamins

____

____

____

(b) Fat-soluble vitamins

____

____

____

4. List the four nutrients that are added to refined white flour to produce enriched white flour.

(a) ____________________ (c) ____________________

(b) ____________________ (d) ____________________

Please check your work with the answers given on page 26.

ANSWERS TO THE KEYED EXERCISES

Exercise 1, pp. 7 and 8.

1. Complete the statements with the words given below.

(1) **organic**
(2) **carbon**
(3) **hydrogen**
(4) **oxygen**
(5) **sucrose**
(6) **glucose**
(7) **fructose**
(8) **galactose**
(9) **polysaccharides**
(10) **lactose**
(11) **sunlight**
(12) **water**

2. Match the statements with the items given on the right.

C secrete their products into tubes or a chamber
F causes a drop in the glucose level in the blood
G only elicits a response from the target organ(s)
E causes an increase in the glucose level of the blood
D secrete their products directly into the bloodstream
A can be converted to glucose by the liver to raise the blood glucose level

A. glycogen
B. thyroxin
C. exocrine glands
D. endocrine glands
E. glucagon
F. insulin
G. hormones
H. vitamins

3. The six major classes of nutrients are:

(a) **carbohydrates**
(b) **fats**
(c) **proteins**
(d) **water**
(e) **vitamins**
(f) **minerals**

Exercise 2, pp. 16 and 17.

1. Complete the statements with the words given below.

(1) **triglyceride**
(2) **cholesterol**
(3) **Plant**
(4) **genes**
(5) **DNA**
(6) **protein**
(7) **arteriosclerosis**
(8) **size**
(9) **Enzymes**
(10) **22**

2. Indicate whether the statement is TRUE or FALSE.

(a) **False** - Salmon, mackeral and herring are high dietary sources of **polyunsaturated** fatty acids.

(b) **True**

(c) **True**

(d) **False** - The process by which proteins lose their characteristic three-dimensional structure is known as **denaturation.**

(e) **False** - The four possible nitrogenous bases in DNA are; adenine, guanine, cytosine and **thymine.**

(f) **True**

(g) **False** - Fat is a more concentrated fuel because it contains more **carbon** atoms.

3. Match the following statements with the items given on the right.

C a nitrogenous base found only in RNA

F genetic material with a thread-like structure

I inactivate or destroy foreign proteins

A. nucleotide
B. thymine
C. uracil
D. cytosine

J	precursor for the hormone, estrogen
H	specific protein catalysts which speed up reactions
B	a nitrogenous base found only in DNA
A	the basic repeating unit of nucleic acids
E	help regulate overall body conditions

E. hormones
F. chromatin
G. chromosomes
H. enzymes
I. antibodies
J. cholesterol
K. deoxyribose

Exercise 3, pp. 22 to 24.

1. Match the following statements with the items given on the right.

J	the process of splitting a molecule by adding water
E	the process of building more complex molecules by removing water
A	a structural component of bones and teeth
K	a molecule that combines with an inactive protein to form an active enzyme
D	necessary for the formation of a component of gastric juice
C	the replacement of lost nutrients to original levels
I	the addition of any nutrient, in any amount, to a food substance
G	aids in the retention of water by the large intestine
F	strengthens tissues by bonding adjacent proteins together

A. calcium
B. emulsification
C. enrichment
D. chlorine
E. dehydration synthesis
F. sulfur
G. fibre
H. cholesterol
I. fortification
J. hydrolysis
K. coenzyme
L. vitamin C

2. Complete the statements with the words given below.

   (1) **evaporation**
   (2) **vitamins**
   (3) **hydrogen**
   (4) **oxygen**
   (5) **heavy metals**
   (6) **iron**
   (7) **Fluoride**
   (8) **vitamin C**
   (9) **bacteria**
   (10) **large intestine**

3. Vitamins are divided into two major groups. List at least three examples for each of the following.

   (a) Water-soluble vitamins
   Vitamin C, the B complex of vitamins - (Thiamine (B_1), Riboflavin (B_2), Niacin (B_3) and Vitamin B_{12})

   (b) Fat-soluble vitamins
   Vitamin A, Vitamin D, Vitamin E and Vitamin K

4. The four nutrients that are added to refined white flour to produce enriched white flour are:

   (a) **iron**
   (b) **thiamin***
   (c) **riboflavin**
   (d) **niacin**

*Notice that thiamin can also be spelled with an "e" at the end, thiamine.

EXERCISES TO BE SENT IN FOR CORRECTION

Part One: Multiple Choice

For each of the following questions, choose the best answer and write the appropriate letter in the blank provided.

_______ 1. Which one of the following groups of elements make up sugars and fats?

(a) Na, Cl
(b) C, H, O, N, S
(c) Ca, K, Mg, Fe
(d) C, H, O

_______ 2. Proteins are composed of many simpler units called

(a) amino acids.
(b) fatty acids.
(c) monosaccharides.
(d) glycerides.

_______ 3. Which one of the following foods provides the mineral element needed for the healthy functioning of the thyroid gland?

(a) oranges
(b) rice
(c) seafood
(d) kidneys

_______ 4. Which of the following groups of compounds is the body capable of oxidizing to produce energy?

(a) carbohydrates, fats, vitamins
(b) carbohydrates, fats, proteins
(c) minerals, proteins, vitamins
(d) fats, proteins, minerals

_______ 5. The major carbohydrate stored in the human body is

(a) glucose.
(b) fat.
(c) glycogen.
(d) starch.

_______ 6. Studies seem to indicate that the blood cholesterol level may rise with an increased daily consumption of

(a) polyunsaturated fatty acids.
(b) saturated fatty acids.
(c) nucleic acids.
(d) amino acids.

________ 7. A DNA molecule is composed of thousands of repeating units known as

(a) nucleotides.
(b) nucleic acids.
(c) amino acids.
(d) nucleases.

________ 8. The process of splitting a molecule by adding water is known as

(a) dehydration synthesis.
(b) emulsification.
(c) respiration.
(d) hydrolysis.

________ 9. Which of the following is NOT a fat-soluble vitamin?

(a) vitamin A
(b) vitamin C
(c) vitamin D
(d) vitamin E

________ 10. Which one of the following minerals is necessary for the formation of a component of gastric juice?

(a) sulfur
(b) chlorine
(c) sodium
(d) potassium

________ 11. Which one of the following nitrogenous bases can be classified as a purine?

(a) guanine
(b) cytosine
(c) thymine
(d) uracil

________ 12. Protein catalysts, which increase the rate of reactions within the body, are called

(a) buffers.
(b) hormones.
(c) pyrimidines.
(d) enzymes.

________ 13. Those fatty acids which possess more than one double bond between their carbon atoms are called

(a) saturated fatty acids.
(b) monounsaturated fatty acids.
(c) amino acids.
(d) polyunsaturated fatty acids.

________ 14. The main energy reserves of plants are made up of the carbohydrate,

(a) glucose.
(b) starch.
(c) cellulose.
(d) fructose.

________ 15. The indigestible material which is referred to as plant fibre is actually the polysaccharide,

(a) starch.
(b) cellulose.
(c) glycogen.
(d) sucrose.

________ 16. Those proteins which are produced in response to foreign proteins are called

(a) bacteria.
(b) enzymes.
(c) antibodies.
(d) toxins.

________ 17. Which of the following is NOT an acceptable base pairing for a nucleic acid?

(a) adenine - thymine
(b) adenine - uracil
(c) cytosine - guanine
(d) cytosine - uracil

________ 18. Which vitamin is produced by the skin when it is exposed to sunlight?

(a) some B vitamins
(b) vitamin D
(c) vitamin E
(d) vitamin K

________ 19. The proper absorption of calcium and phosphorus requires the presence of

(a) vitamin C
(b) vitamin D
(c) vitamin E
(d) vitamin K

________ 20. The removal of an amine group from an amino acid is called

(a) emulsification.
(b) denaturation.
(c) protein synthesis.
(d) deamination.

________ 21. Which of the following is NOT a monosaccharide?

(a) maltose
(b) glucose
(c) fructose
(d) galactose

________ 22. The only class of organic nutrients which is NOT digested by the human body is the

(a) proteins.
(b) vitamins.
(c) nucleic acids.
(d) carbohydrates.

________ 23. Which of the following would be a symptom of vitamin A deficiency?

(a) rickets
(b) scurvey
(c) night blindness
(d) anemia

________ 24. The blood glucose level is monitored and controlled by the

(a) pituitary.
(b) liver.
(c) pancreas.
(d) adrenal gland.

________ 25. Those amino acids which cannot be produced by the human body are called

(a) essential amino acids.
(b) vitamins.
(c) plant proteins.
(d) non-essential amino acids.

Part Two: Matching and Fill in the Blanks

1. Match the following by choosing the correct letter from column II and place it in the appropriate blank in column I. DO NOT use any letter more than once.

Column I

______ major source of stored energy in the human body

______ a major structural component of hair, nails and skin

______ inorganic molecules essential in small amounts

______ essential for heredity and protein synthesis

______ makes up about 65% of the total body weight

______ main source of fuel for the human body

______ essential organic molecules which are often part of coenzymes

Column II

A. carbohydrates
B. proteins
C. fats
D. fibre
E. water
F. nucleic acids
G. hemoglobin
H. minerals
I. vitamins

2. Complete each of the following statements by filling in the numbered blank on the right.

(a) Organic compounds are those which contain ___(1)___ . (1) ______________

(b) ___(2)___ is often called milk sugar because it is produced in the mammary glands of mammals. (2) ______________

(c) Green plants use carbon dioxide, sunlight and water to produce the carbohydrate ___(3)___ . (3) ______________

(d) Most fats present in the body are in the form of ___(4)___ . (4) ______________

(e) Those proteins in the blood which help to maintain a constant pH are called ___(5)___ . (5) ______________

(f) The process involving the removal of water to form a larger, more complex molecule is called ___(6)___ ___(6)___ (two words). (6) ______________
____

(g) A ___(7)___ combines with a protein to form an active enzyme. (7) ______________

(h) Starches are the main energy reserves in plants because they are ___(8)___ in water.

(8) __________

(i) ___(9)___ stimulates the liver and muscle cells to convert ___(10)___ to ___(11)___ when the blood glucose level is low.

(9) __________

(10) __________

(11) __________

(j) ___(12)___ are chemical messengers sent via the bloodstream to target organs which they regulate.

(12) __________

(k) ___(13)___ overconsumption has been implicated in either causing or setting the stage for diseases like diabetes, high blood pressure or hyperactivity.

(13) __________

(l) A nucleotide consists of three parts; a ___(14)___, a ___(15)___ and a ___(16)___.

(14) __________

(15) __________

(16) __________

(m) During a carbohydrate shortage in the diet, the body must break down ___(17)___ and ___(18)___ to meet its energy requirements.

(17) __________

(18) __________

(n) Most of the cholesterol required by the body is manufactured by the ___(19)___.

(19) __________

(o) RNA plays a major role in the transfer of information from the DNA molecule to the ___(20)___.

(20) __________

Part Three: Short Answer

1. Homemade soups, with a layer of liquid fat floating on the surface, often seem to taste and smell better than canned soups. Why is this?

____

____

____

____

____

2. Give four ways by which vitamins, that may be present in food, are sometimes lost before they are eaten.

3. Why is brown whole wheat bread more nutritious than white bread?

4. Would the pH of the blood change if you ate acidic food?

   (a) Explain your answer.

5. Everyone should take a multi-vitamin tablet daily to supplement their diet.

   (a) Is this statement true or false?

   ____

   (b) Explain your answer.

   ____

   ____

   ____

   ____

   ____

   ____

   ____

   ____

Part Four: Laboratory Investigations

Investigation 1: Carbohydrates

Purpose

To identify carbohydrates.

Background

As noted in your teaching notes earlier in the lesson, there are three classes of carbohydrates; monosaccharides, disaccharides and polysaccharides. These various carbohydrates can be identified by using specific kinds of reagents.

Benedict's solution is a reagent used to identify certain types of carbohydrates. Specifically this reagent will only react with carbohydrates that are easily oxidized. Such carbohydrates are referred to as **reducing sugars**. Generally monosaccharides and some disaccharides are oxidized easily with Benedict's solution.

Benedict's solution (blue in color) is added to the substance to be tested and then heat is applied. If simple sugars are present, the blue color will change to any of the following colors; light green, yellow, orange, red or brown. The more sugar there is, the darker the solution will be. A failure to change from the original blue after heating means that the solution **does not** contain any simple sugars.

The presence of complex carbohydrates like starch can be identified with a **dilute iodine solution**. A change to a blue-black color is a positive test for the presence of starch in a substance.

Note: When testing different solutions to see whether they contain a specific carbohydrate, there should always be a control group. The control group would be a solution (water) that lacks the carbohydrate being tested for. When the testing reagent is added to the control group, it should not change color, thus indicating the neutral condition for the reagent. When the reagent is added to the experimental groups, it should change color in those groups that contain the carbohydrate being tested for. By comparing the experimental groups to the control group, you can tell which of the experimental groups contain the specified carbohydrate because the reagent will have changed color in these solutions.

Materials Required to Complete the Experiments

Glassware	- beaker or cup (for water bath) - test tubes (13 mm × 100 mm) - eye dropper
Reagents	- Benedict's solution - Iodine solution (See page 12 of Introduction.) - glucose (dextrose) solution Dissolve 2 g (½ teaspoon) of glucose in 50 ml of warm water - milk (powdered or fluid) - starch solution (See page 12 of Introduction.) - crushed fruit (orange, apple or banana) - unknown A (only in lab kit about 5 g of solute in 50 mL of water) - common table sugar (about 5 g sugar in 50 mL of water) - glycogen solution (if available) (See page 12 of Introduction.)
Other Supplies	- boiling water

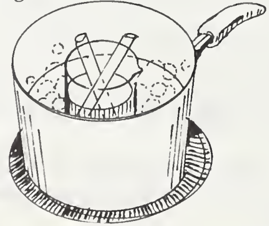
Note: After completing **all** the laboratory investigations in Lesson 4, refer to p. 11 of the Introduction to Biology 30. This describes the correct methods of safely disposing of the chemicals used in these investigations.

Procedure

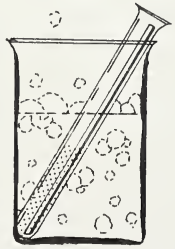
1. Test for Reducing Sugars

- Take one clean test tube and half fill it with water. Label this tube "water".
- Take another clean test tube and half fill it with a glucose solution. Label this tube "glucose".
- **Add** one eye dropper full of **Benedict's solution** to each tube.
- Place both test tubes into boiling water. You may use either a water bath or simply a large glass or beaker filled with boiling water. (see the diagrams below).

CAUTION:
DO NOT place plastic beaker directly on the burner. **Boiling water and steam can cause burns.**



Water Bath
(Beaker of water in a pot of boiling water)

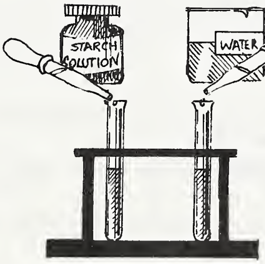


(Boiling water in beaker)

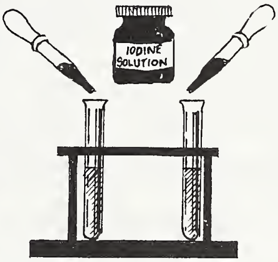
- **Heat the mixtures** in the boiling water **for two or three minutes.**
- Remove the test tubes and **record your observations** in the table provided (p.38).
- **Repeat this procedure** for each of the following substances; milk, starch solution, fruit, unknown A solution and common table sugar.
- After completing this test for all of the substances, clean your glassware thoroughly.

2. Test for Starch

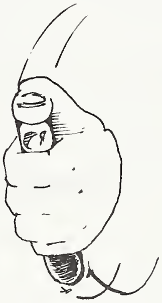
- Half fill a clean test tube with water and add several drops of iodine solution to this. Record the color, if any. Keep this sample as a comparison with other tests in this series.
- Half fill a clean test tube with a starch solution and add **two or three drops** of iodine solution. **Shake the tube and record the color,** if any, in the table provided on page 38.



Step 1



Step 2



Step 3

- **Repeat this procedure** for each of the other substances; glucose solution, glycogen solution, fruit in solution and unknown A.
- **Record your observations** in the table provided.
- After you have completed the tests, **clean your glassware** thoroughly.

Results

1. **Test for Reducing Sugars** (Add Benedict's Solution and Heat)

Test Tube No.	Substance Tested	Color Observed After Heating
1	water	
2	glucose solution	
3	milk	
4	starch solution	
5	fruit used ________	
6	unknown A	
7	common table sugar	

2. **Test for Starch** (Add dilute Iodine solution)

Test Tube No.	Substance Tested	Color Observed
1	water	
2	starch solution	
3	glucose solution	
4	glycogen solution (if available)	
5	fruit used ________	
6	unknown A	

Questions

1. The test tube of water was used for comparing color differences in the first series of tests. This is called a control. What is the purpose of a control?

2. Do all types of sugars react positively with Benedict's solution? Verify your answer by referring to your observations.

3. From your observations what information have you gained about unknown A?

4. In what form are excess carbohydrates stored

   in animals? ____________________

   in plants? ____________________

5. Is the iodine solution useful for distinguishing between starch and glycogen?

Investigation 2: Lipids (Fats and Oils)

Purpose

To identify fats in substances.

Background

The presence of a high percentage of fats in a substance can easily by identified by the **grease spot test**. In this test, a drop of oil is placed on a sheet of unglazed brown paper such as wrapping paper or a paper bag. The paper is let to dry and then examined. If a transluscent grease mark is left on the paper, you can conclude that the substance contains a fat.

Substances with a low percentage of fats can be tested with a reagent called **Sudan IV dye.** Sudan IV is insoluble in water but is soluble in a fat. Thus if a substance has any fat in it, the dye dissolves in it and leaves a reddish color.

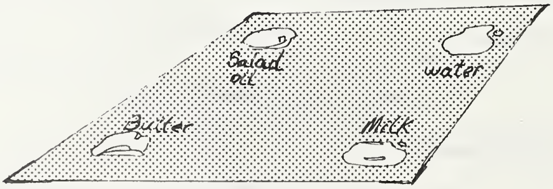
Materials Required to Complete Experiment

Glassware	- eyedropper (or you can simply place droplets of oil from the jar into the tubes) - test tubes
Reagents	- Sudan IV - salad oil - uncooked animal fat or bacon - cream - butter or margarine
Other Supplies	- unglazed brown paper (wrapping paper, paper bags, etc) - test tube rack (See page 9 of Introduction.) - waxpaper

Procedure

1. Grease Spot Test

- **Place one or two drops** of salad oil on a corner of a sheet of unglazed paper and label it.
- **Spread** the salad oil as thinly as possible over a small area.
- **On each of the next three corners** place and spread a few drops of water, a few drops of milk and on the fourth corner place a smear of animal fat or butter or margarine.
- **Label each corner**.
- **Set this aside to dry** for at least 30 min.
- Examine the paper by holding it up to the light and look for any transluscent spots.
- **Record your observations** in the table on page 41.



Brown paper with smears of substances to be tested.

2. Sudan IV Dye Test

- To approximately 2 cm of water in a small test tube add about 1 cm of salad oil.
- Add a small amount (only a few grains) of Sudan IV dye.
- Close the end of the tube with your fingers and **shake the contents vigorously.**
- Allow this to stand for a few minutes.
- Examine the contents and **record your observations** in the diagram on page 42.
- To approximately 2 cm of milk in a small test tube add a few grains of Sudan IV. **Observe and record** the results.
- To approximately 2 cm of cream in a small test tube add a few grains of Sudan IV. **Observe and record** the results.
- Place a smear of butter or margarine on a piece of wax paper, add several grains of Sudan IV dye to this and mix the two together. Examine this and **record your observations.**
- Once you have completed the exercise and recorded your observations, **clean and rinse all your glassware and equipment** thoroughly.

Results

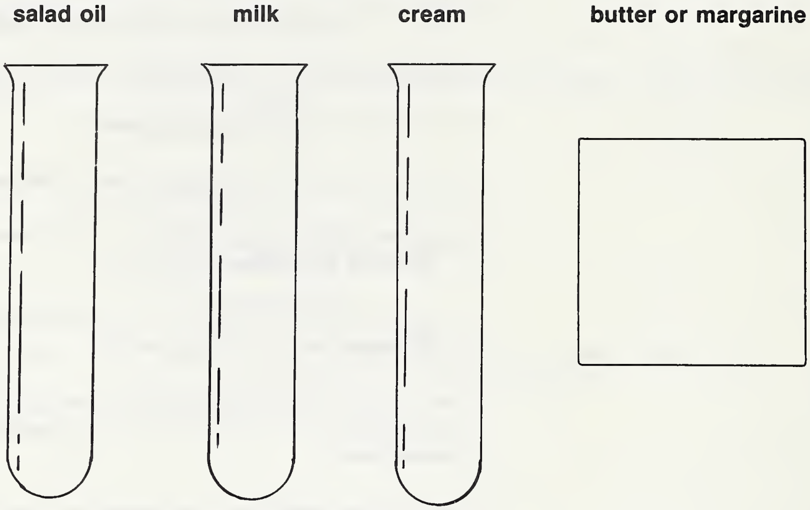
1. Grease Spot Test

Substances Tested	Observations
Salad oil	
Water	
Milk (Homo, 2% or Skim)*	
Uncooked animal fat or bacon*	
Butter or margarine*	

*Circle the substance used.

2. **Sudan IV Test**

(a) Diagram your observations and label.



(b) Indicate any color changes

Questions

(1) From the experimental results, would you conclude that your milk sample contains fat? Explain.

(2) How would you establish a control for the Sudan IV dye test?

3. (a) Devise a simple test to determine whether or not peanuts contain lipids.

(b) Now test your procedure and state your conclusion.

Investigation 3: Proteins

Purpose

To identify proteins in a substance.

Background

The presence of proteins can be identified by using various reagents. The most common reagent used is **Biuret**. When Biuret is added to a compound containing proteins it gives a pink to purple color.

Materials Required to Complete the Experiment

Glassware	- eye droppers - test tubes (13 mm × 100 mm)
Reagents	- Biuret reagent - albumin solution (See page 10 of Introduction.) - egg yolk - gelatin solution (about 5 g in 50 mL of water) - milk - unknown A solution (about 5 g in 50 mL of water)

Procedure

- Fill a small test tube about a quarter full of water and add 5 drops of Biuret reagent to it.

- Similarly fill small test tubes with egg yolk solution, egg albumin solution, gelatin solution, milk and solution of unknown A. Add 5 drops of Biuret reagent to each test tube.
- Gently shake the tubes to mix the solutions.
- Observe the results for all tests and **record the results** in the table provided.
- Once you have completed the exercise and recorded your observations, clean and rinse all your glassware and equipment thoroughly.

Results

Biuret Test

Substances Tested	Color Changes Observed
water	
egg yolk	
egg albumin	
gelatin	
milk	
unknown A	

Questions

1. Concentration of protein varies according to the type of food.

   (a) What color would you expect to find after testing a food sample of relatively low protein content with Biuret reagent?

   ____

   (b) What color would you expect to find after testing a food sample of relatively high protein content with Biuret reagent?

   ____

2. Of all the substances you tested, which ones would you say have proteins in them?

   ____

3. Explain what a high protein diet would be. Give examples of foods eaten in such a diet.

Please submit pages 28 to 45 for correction.

END OF LESSON 4

LESSON RECORD FORM

3230 Biology 30

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ALBERTA CORRESPONDENCE SCHOOL

MAILING INSTRUCTIONS FOR CORRESPONDENCE LESSONS

1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

First Class

Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

OBJECTIVES

Upon completion of this lesson material the student will be able to carry out the following correctly:

1. **Distinguish** between mechanical and chemical digestion.
2. **Name** the enzyme in saliva and identify its function.
3. **List** three broad categories of carbohydrates.
4. **Trace** the digestive process to which carbohydrates are subjected in the human digestive tract.
5. **Identify** the functions of bile.
6. **Identify** correctly the end products of protein digestion.
7. **Explain** the function of lipase in the digestive tract.
8. **Identify** three categories of control to which the release of digestive enzymes are subjected.
9. **List** four hormones that control enzyme secretion. Identify their sources.
10. **Explain** what factors and/or processes aid the absorption of nutrients into the blood and lymph.
11. **Identify** the functions of the large intestine.
12. **Explain** the respective causes of diarrhea and constipation.
13. **List** the normal contents of the material in the large intestine.
14. **Identify** four malfunctions of the digestive system and list probable causes of each.
15. **Define** peristalsis and identify the digestive region in which it occurs.
16. **Differentiate** between intracellular and extracellular digestion.
17. **Explain** how enzymes are named.
18. **Explain** the nature and function of co-factors (co-enzymes).
19. **Explain** how pH is measured.
20. **Explain** why the lining of the stomach is not normally digested by enzymes.
21. **Comprehend** the significance of the hepatic portal vein.
22. **Discuss** the digestion of fats following removal of the gallbladder.

THE PROCESS OF DIGESTION IN MAN

Assigned Reading: pp. 301 - 320, text: *Biology of Ourselves,* **by Gordon S. Berry et al.**

Introduction

Humans are unable to synthesize their own food. For their food requirements they must depend on green plants which are able to synthesize food utilizing carbon dioxide and water in the presence of light.

Man must locate, ingest (eat) and digest food in order to supply the food required by the body. The ingested foods normally consists of insoluble large molecules. These insoluble, large molecules must be broken down into soluble compounds having molecules small enough to enter cells. In order to be useful to the body, digested foods (small molecules in solution) must pass through the walls of the intestine and enter the bloodstream. Blood picks up the digested food and transports the food to all body cells. Body cells utilize the food for energy production, growth, repairs and reproduction. The majority of body cells obtain their energy from combining the chemicals in food with oxygen. The chemicals from digested food are utilized by many cells to replace worn out, damaged or dead cells, for the production of new cells and for cell growth.

As you study the process of digestion, you will recognize that the human body is unable to utilize all the food materials ingested. There are insoluble wastes left over following the process of digestion. In addition to the insoluble waste, human body cells also produce chemical wastes (metabolic wastes). The body must be able to eliminate these materials which are potentially toxic. Insoluble wastes must be effectively eliminated as well.

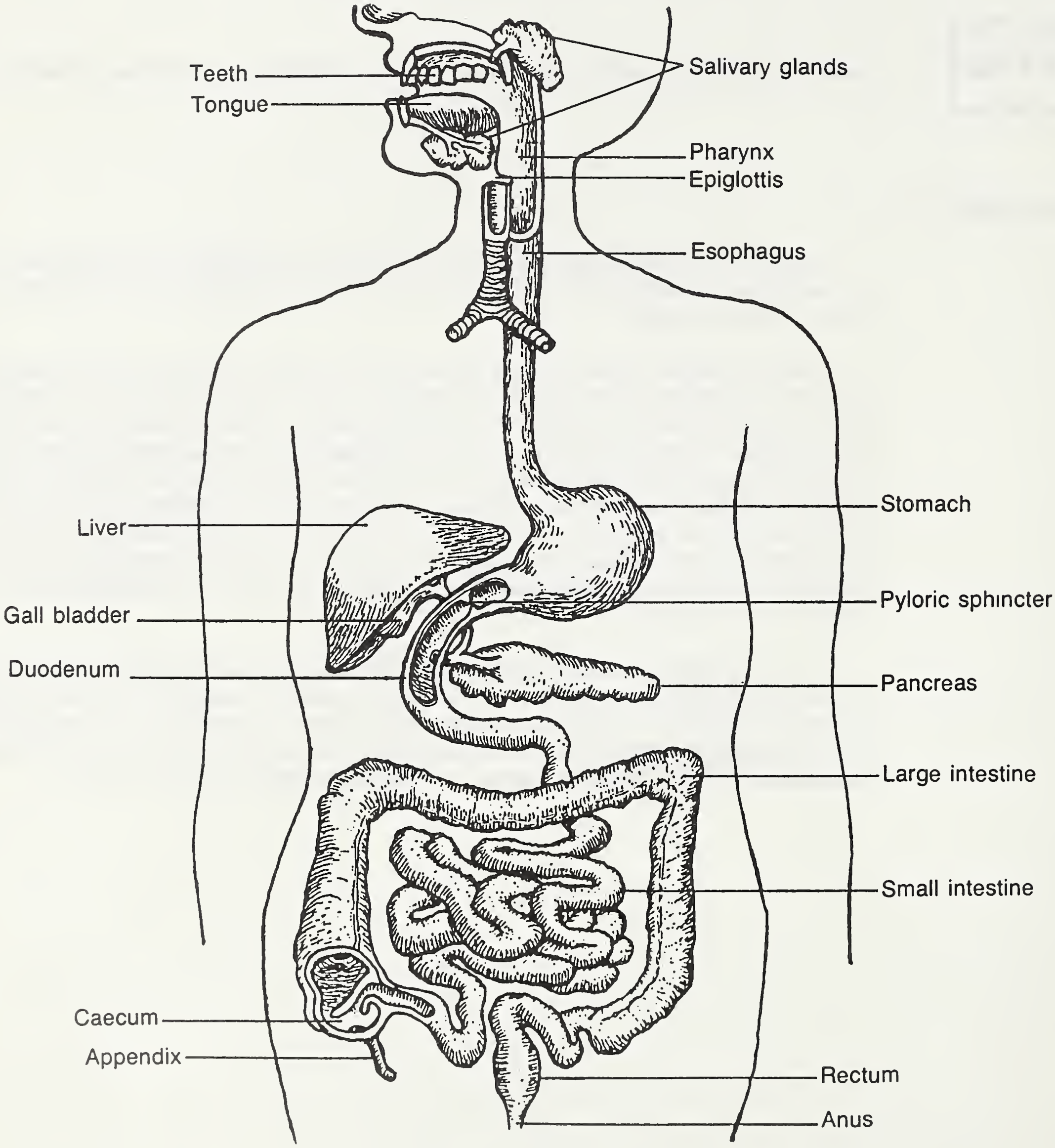


Figure 1: Digestive system of the human.

The Digestive Process

In lesson 3 of this course we studied the structure of the digestive system of man. This lesson deals with the process of digestion.

The digestion of food involves two alteration processes. One process involves the **mechanical alteration** of food; the other process involves the **chemical** breakdown of food.

Mechanical alteration breakdown of food preceeds **chemical breakdown** or **digestion**. Mechanical breakdown is important for at least two reasons. One reason is that this process prepares the food for swallowing. A second reason is that mechanical breakdown significantly increases the surface area of the food to be digested. The increased surface area facilitates the action of digestive enzymes.

Mechanical breakdown reduces the size of food particles. This reduction in the size of food particles enable digestive enzymes to act on them effectively. The other aspect of mechanical digestion involves two kinds of movements. One of these movements is called **peristalsis**, a wave-like series of contractions of the walls of the digestive system. **Peristalsis** occurs, and can be observed in all parts of the digestive system excluding the mouth and the **pharynx**. Peristalsis produces a double effect on the food by moving it along the digestive system as well as mixing it thoroughly.

Another kind of movement occurs in the small intestine. This kind of movement involves non-wavelike rhythmic contractions that serves to mix the food even more.

Intracellular vs Extracellular Digestion

In many heterotrophic organisms including man, digestion is **intracellular**, that is, the process occurs after the solid food has been engulfed by the cell. The amoeba is one such organism. It flows around its food, surrounding it completely. This results in the creation of a small space with the food and fluid that is engulfed within the organism. This space is now a **food vacuole**. To digest the food, the cell secretes **digestive enzymes** into the food vacuole. The enzymes break down the food into small usable molecules. From the food vacuole the usuable materials pass through the membranes of the vacuole and enter the cell for use. The indigestible parts of the food are discharged to the outside of the cell.

Extracellular Digestion

Many heterotrophs utilize another solution to the problem of digesting food. That is, they secrete digestive enzymes from the cell, digesting the food outside the cell. This constitutes **extracellular digestion**. The digested food, having been reduced to small soluble molecules such as glucose and amino acids can pass by the process of diffusion and active transport across the cell membrane and into the cell. Most animals including humans digest their food **extracellularly**. This type of digestion is common among animals that have digestive systems with two openings; an **anterior** opening, the **mouth** through which food enters and a **posterior** opening, the **anus**, through which waste is egested.

Enzymes and Chemical Digestion

With the exception of mineral salts and vitamins, alcohol and certain drugs, all foods ingested by humans require chemical breakdown. When humans ingest mineral salts and vitamins, these substances dissolve and form particles small enough to enter body cells for immediate use.

Chemical breakdown of foods is brought about by **digestive enzymes**. Digestive enzymes act as catalysts in biological systems. They significantly affect the rate of chemical reactions without themselves being changed. Furthermore, enzymes do not become part of the end products of enzymatic reactions. Precisely how enzymes affect chemical reactions has not been identified. Some researchers believe that each enzyme affects the reaction by providing a foundation or surface upon which chemical reactions may take place. Recall that enzymes are known to be specific in their action. In other words each enzyme is specific with respect to the kind of food it may react with. For example, an enzyme that breaks down carbohydrates will not similarly affect fats or oils and proteins.

The significance of enzymatic reactions in biological systems should not be underestimated. For example, biochemists have concluded that without enzymes, many chemical reactions would not occur rapidly enough at ordinary temperatures to sustain life. Moreover, many chemical reactions in living organisms require activation energy initially. Enzymes, like other catalysts, reduce the amount of **activation energy** required for chemical reactions.

All chemical reactions require some energy to start them. This energy is called **activation energy**. A low activation energy of molecules permit the molecules to undergo rapid chemical changes at relatively low temperatures. In living systems enzymes permit chemical reactions such as chemical breakdown to occur in the presence of a small amount of activation energy.

Enzymes are indispensible to the bodies of multicellular organisms if they are to produce sufficient energy to carry out such processes as muscle contraction, nerve conduction, excretion and absorption.

The chemical compounds upon which enzymes act are called **substrates**. The compounds that are produced as a result of the enzyme—substrate reaction are called **products**.

Coenzymes

Some enzymes, in order to function efficiently, require the assistance of a small molecule called a **coenzyme**. Structurally, parts of coenzymes are **vitamins** such as **riboflavin** (vitamin B_2), and thiamin (vitamin B_1). Moreover, there are **inorganic cofactors** which are sometimes required for effective enzyme action. Inorganic cofactors such as **iron** and **copper** are sometimes necessary for the transfer of electrons. Biologists believe that in living systems, copper plays a role in electron transport. Another example of an inorganic cofactor is magnesium which is known to be essential for the transfer of phosphate in living systems.

In summary, an enzyme serving as a catalyst in a living system is a protein in nature. Sometimes an enzyme by itself is not enough to function as a catalyst. Frequently, one or more coenzymes or cofactors may be necessary.

Enzymes and Reaction Rates

In the absence of the appropriate enzymes, many biochemical reactions proceed at a very slow rate. Ongoing research in different areas of the biological sciences have provided evidence to the effect that virtually all biological systems are controlled by enzymes.

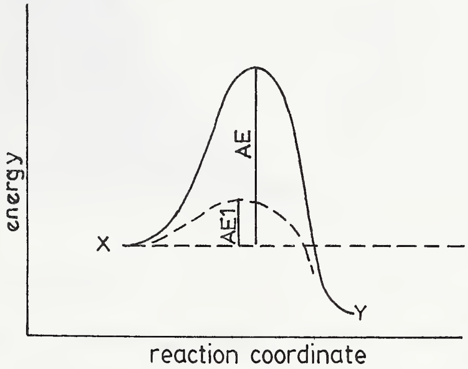


Figure 2: A graph that shows how enzymes increase the efficiency of biochemical reactions. In the conversion of substance X into substance Y a certain amount of activation energy (shown as AE) is required. However, with the proper enzyme, much less energy (shown as AE1) is required for activation. Most, if not all, chemical reactions in living cells utilize enzymes in this manner.

Recall, that enzyme action is specific. The surface of a given enzyme, therefore will fit with only one substrate or one type of substrate. Normally, any one enzyme will act on only one kind of molecule.

As a rule enzymes do not participate permanently in the chemical change they promote. Upon completion of the chemical change, the enzyme is released unchanged. In this way an enzyme may be used and be re-used several times within the same system. In any single cell, only small amounts of any enzyme are present. Any one cell may carry out upwards of a thousand chemical reactions each of which requires a different enzyme.

The Nature of Enzymes

All known enzymes are proteins. Some are wholly protein, others partly so. The protein nature of enzymes reflects certain characteristics of the enzymes themselves. For example, it was discovered that enzymes in living systems are sensitive to heat and the acidity of the environment. High temperatures tend to destroy enzymes so that no further reaction can take place. Recall that boiling water cooks an egg. Actually the boiling water denaturates the egg. Similarly, high temperatures destroy enzymes. Enzymes in biological systems are said to have **optimal temperatures** at which they function best.

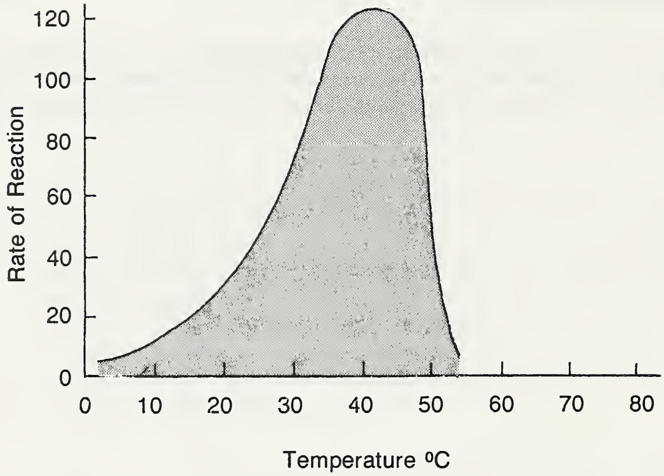


Figure 3: The effect of temperature on an enzyme-catalyzed reaction.

Biologists now know that there are certain critical temperatures above which enzymes cease to function. Study the illustration carefully. You will observe that the reaction rate increases rapidly from 2°C up to about 40°C. Just above this temperature the reaction rate begins to slow. At about the 45°C range the reaction rate starts to decrease. If the destructive temperature is maintained for several minutes, the enzyme may be completely denaturated (inactivated).

It is important to note that different enzymes have different optimal temperatures. Most enzymes in warm-blooded animals function best at a body temperature of 37°C. The optimal temperatures of enzymes imposes limits on where organisms can live. For most warm-blooded animals metabolic activities slow significantly or stop completely at temperatures above 40°C. In some animals, cells are able to change their rate of metabolism. This would mean that for such organisms, as the temperature varies from day to day and from season to season, so does the **intensity of the life processes**.

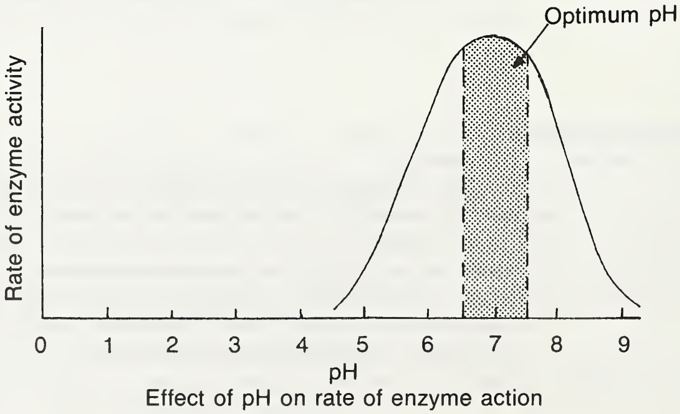


Figure 4: The graph above illustrates the effect of pH upon the rate of enzyme reaction. According to the illustration the optimum pH for most enzymes is approximately 7, the neutral pH. When pH values become relatively high or low enzyme activity slows down markedly.

Self-Correcting Exercise 1 (Answers provided)

1. How does the majority of cells in the body obtain energy? Explain.

2. List two advantages of subjecting food to mechanical breakdown.

   (a) ____________________

   (b) ____________________

3. What is peristalsis?

4. Distinguish between intracellular and extracellular digestion.

   (a) Intracellular: ____________________

   (b) Extracellular: ____________________

5. List two food substances ingested by humans that requires no further digestion before they are absorbed.

   (a) ____________________

   (b) ____________________

6. Give another name for the catalysts in living systems that affect the rate of chemical reactions.

____

7. What are substrates?

____

____

____

____

8. The temperature at which an enzyme is most effective is called ________________.

9. Under what class of nutrient would you list enzymes?

____

10. At what temperature would most enzymes in living systems function best?

____

____

(Check your work with page 42. Correct any errors in your work.

pH

An acid is a substance that releases or donates hydrogen ions (H^+) in solution. The stronger the acid, the more hydrogen ions it releases. One very strong acid is hydrochloric acid. This acid is very strong because nearly all of it separates into hydrogen ions (H^+) and chloride ions (Cl^-) in solution. Vinegar and lemon juice tastes sour because of the acids in them.

Bases readily unite with H^+ ions. Bases tend to feel soapy or slippery to the touch. Ammonia and baking soda are bases. A base such as sodium hydroxide ($NaOH$) in solution separates into Na^+ and OH^- ions. In living tissues the hydroxyl ions (OH^-) combine with the hydrogen ion (H^+) to form water. pH is measured on a scale of 0 - 14. This scale indicates how acidic or basic a solution may be. Pure water for example is considered to be neutral measuring a pH of 7.

A neutral pH (pH7) indicates that the solution is neither acidic or basic (alkaline). Acids generally have a pH of less than 7. Basic (alkaline) substances have pH values greater than 7. Substances with a pH of 1 are very strong acids. The hydrochloric acid of the stomach in humans varies from a pH of 1 to 3. A pH of 14 represents the strongest base.

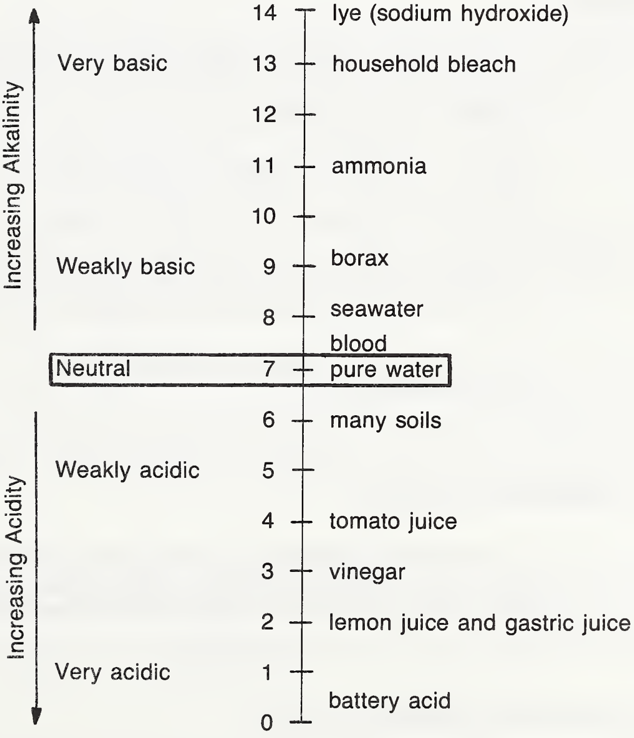


Figure 5: The pH of an assortment of common substances

pH and Enzyme Function

Many enzymes in living systems are sensitive to changes in **pH**. Each specific enzyme functions most effectively in an environment of a particular pH range. For each enzyme pH values above or below its particular optimum diminishes the effectiveness of the enzyme.

Very strong acids and bases pose a danger to living systems because they damage living cells and tissues. Most living cells are very sensitive to changes in the pH of their extracellular fluids. Researchers have repeatedly taken measurements to determine the effectiveness of certain enzymes over the pH range of 1-14. They accomplished this by **observing the amount of products formed at various pH levels at a constant temperature**. The optimum range for enzyme activity is different for each enzyme.

Digestive enzymes of the stomach are most effective in an acidic environment. In fact, stomach contents of humans vary in acidity from pH 1.2 to 3. The pH of human blood plasma varies from pH 7.34 to 7.45. When these limits are exceeded (plus or minus) grave illness or even death may follow.

Naming Enzymes

The enzymes existing in living systems are numerous. A systemic method for naming enzymes has been developed and has been used extensively. The approach involves taking the **prefix** of the **substrate** molecule and adding the **suffix** "**ase**." For example, fat digesting enzymes are lipases, that is, "lipid + -ase." Protein digesting enzymes are the proteinases (protein + -ase). There are exceptions to this approach to the naming of enzymes. For example, enzymes discovered during the early years of the research still retain their original names. Such enzymes include ptyalin (salivary amylase), pepsin and trypsin.

Many enzymes recently discovered, retain their full names. In such cases, the full name of the specific substance (substrate) is used. To this name is added the suffix "-ase."

For example, the enzyme carboxypolypeptidase retains the full name and the suffix "-ase" is added.

The Control of Digestive Secretions

All the digestive enzymes in humans are produced **by body cells**. The appropriate enzyme in each case is **produced only when certain cells are stimulated** to do so. The stimulation required may be provided by **nerve impulses, hormones** or a **combination of both**.

Secretions in the Mouth Controlled by Nerves

As food enters the mouth it is moistened by **saliva**. The secretion of saliva from all three pairs of **salivary glands**, namely, the **parotid**, the **submaxillary**, and the **sublingual** are under the control of the nervous system. The senses of sight, taste and smell, when stimulated, generate impulses that are transmitted to the salivary glands. The salivary glands once stimulated will begin to secrete their juices. Sounds associated with food, or even the thought of food are enough to send nerve impulses to the salivary glands.

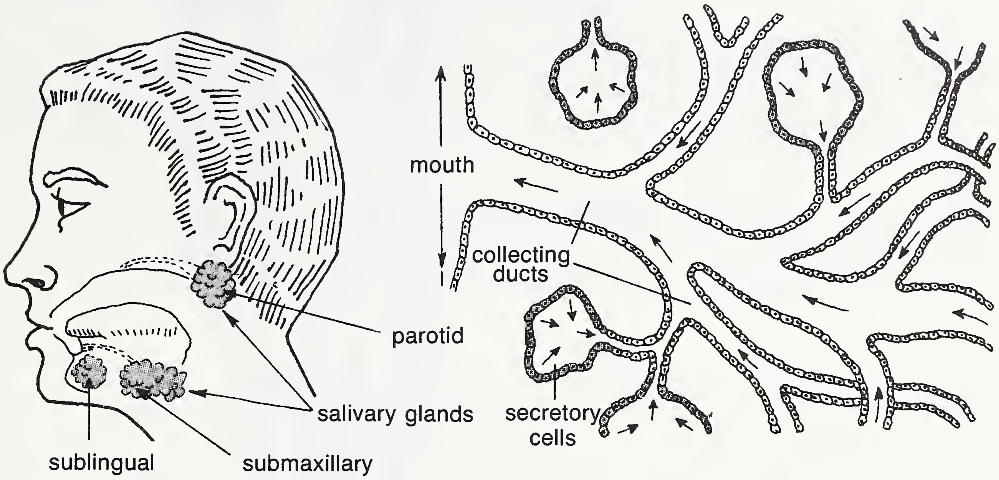


Figure 6: Organization of human salivary glands. These are exocrine glands. Note that the secretions (saliva) pass into a system of ducts which lead to the mouth.

Secretions in the Stomach: Nervous and Hormonal Control

Secretion of gastric juices in the stomach is controlled by both **nerves** and **hormones**. The inner walls of the stomach are lined with millions of gastric glands of several kinds. One kind of gastric gland secrete a dilute solution of hydrochloric acid. Another kind of gland in the stomach can be stimulated to secrete gastric juice.

The initial stimulant in the stomach is undigested food. Undigested food will stimulate secretions in two ways. First, the food present causes the wall of the stomach to stretch. This stretching stimulates nerve receptors of the stomach wall. The receptors of the stomach cause nerve impulses to be transmitted to the brain. From the brain impulses are transmitted back to the stomach. These impulses stimulate the gastric glands of the stomach to secrete **gastric juice**.

Secondly, food in the stomach brings about the production of a hormone called **gastrin**. Undigested food causes **peristalsis**. Peristalsis in turn brings about the stimulation of stomach cells to produce **gastrin**. The hormone gastrin diffuses into the blood stream and is transported throughout the body. As blood containing gastrin returns to the stomach, the gastric glands are stimulated to produce more gastric juice.

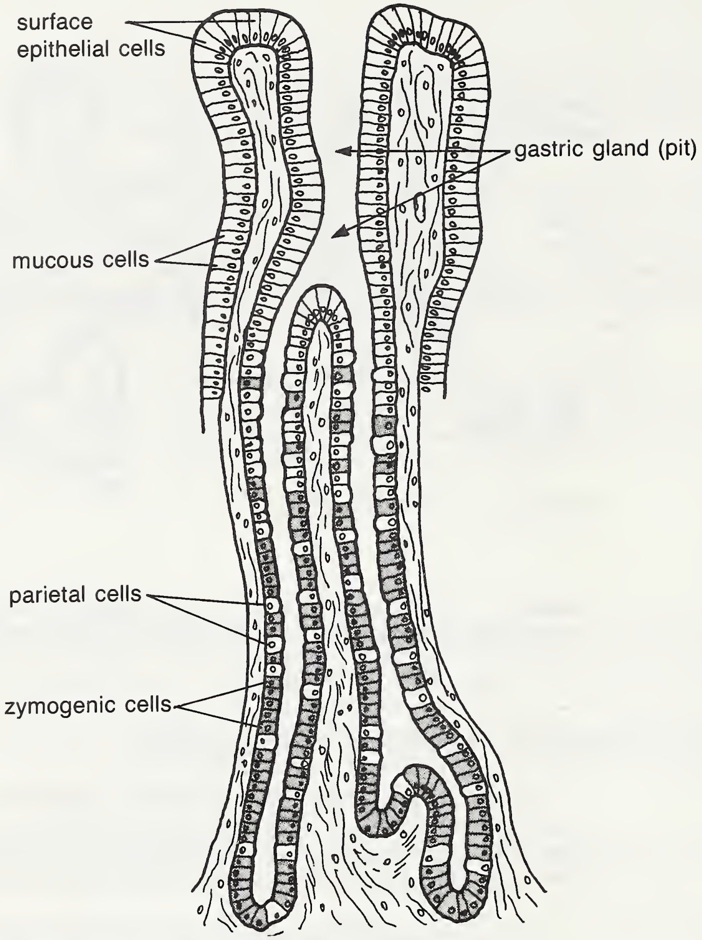


Figure 7: The gastric glands from the wall of the stomach.

As food moves out of the stomach and enters the small intestine the signals for secretion of gastric juice and bile stop. Furthermore, as food enters the small intestine, the intestinal walls produce their own hormone that slows down the production of gastric juice.

Secretion of Pancreatic Juice: Duodenum

The secretion of pancreatic juice is under hormonal control. The hormones **secretin** and **pancreozymin** control the release of pancreatic juice.

When the acidic contents of the stomach enters the duodenum, certain cells in the wall of the duodenum release these hormones into the bloodstream. As blood is circulated, the hormone is transported to all parts of the body. Upon reaching the pancreas, **secretin** stimulates its cells to produce and discharge pancreatic juice. More specifically secretin controls the release of the sodium bicarbonate solution in pancreatic juice. The hormone **pancreozymin** is specifically responsible for the release of the digestive enzymes in pancreatic juice. As the pH of the food undergoing digestion in the small intestine becomes basic the production of secretin stops. Without the effects of the hormone secretin, pancreatic secretions cease.

The Secretion of Bile: The Duodenum

The secretion of the liver, bile, plays a significant role in the digestion of fats. The production and secretion of bile by the liver is a continuous process but when bile is not required it accumulates in a storage organ, the **gallbladder. Bile** is released into the duodenum only when the hormone **cholecystokinin** is present. This hormone is produced only when food containing fat comes into contact with the cells of the small intestine that produces it.

The contents of bile include bile salts, water, and other substances dissolved in a basic solution. Bile salts are not enzymes. They emulsify fats and oils increasing their surface area in preparation for digestion by the enzyme **lipase**. Bile salts also help in the preparation of lipids for absorption. They also help to modify the pH of food, changing the pH to slightly basic.

HORMONAL CONTROL OF DIGESTION IN STOMACH AND SMALL INTESTINE

HORMONE	WHERE PRODUCED	STIMULANT	ACTION
Pancreozymin	Duodenum	Acidity of stomach contents	Causes release of enzymes in pancreatic juice.
Stomach gastrin	Stomach lining	Proteins	Causes gastric glands to secrete gastric juice
Intestinal gastrin	Intestinal lining	Partially digested proteins	Same as above.
Secretin	Intestinal lining	Acidity of chyme	Stimulates secretion of pancreatic juice rich in bicarbonate and promotes production of bile by liver.
Cholecystokinin	Intestinal lining	Fats	Stimulates secretion of pancreatic juice rich in enzymes
		Combination of acid and fat	Causes ejection of bile from gallbladder
Enterogastrone	Intestinal lining	Fats	Inhibits secretion of gastric juice and decreases gastric motility

Table 1: Hormonal Control

Major Food Categories

At this point in the lesson we will examine the major categories of foods and their primary sources. We will follow the process of digestion for these categories and examine the end products.

The Carbohydrates

Recall that **starches** make up one of the three common carbohydrates, the other two being **sugars** and **cellulose**. In both plants and animals sugars of varying complexity are present.

Sugars

Monosaccharides

Simple sugars: **simple sugars** or **monosaccharides** (mon-uh-sack-ur-rdez) are of great significance in living systems. One monosaccharide, glucose, is widespread in both plant and animal cells where it is widely used as a fuel. The monosaccharide, **glucose**, goes by other names such as **dextrose, grape sugar** and **blood sugar**.

Two other fairly common monosaccharides are fructose and galactose.

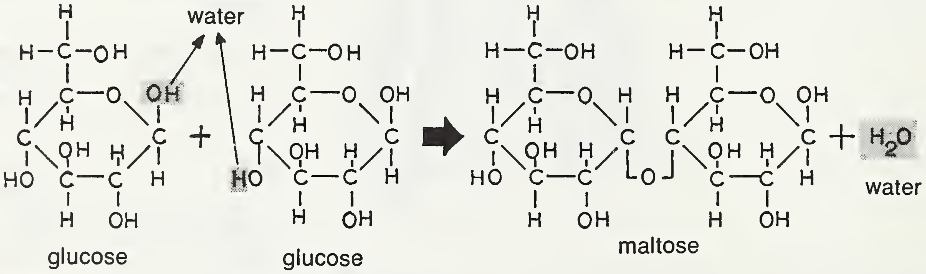


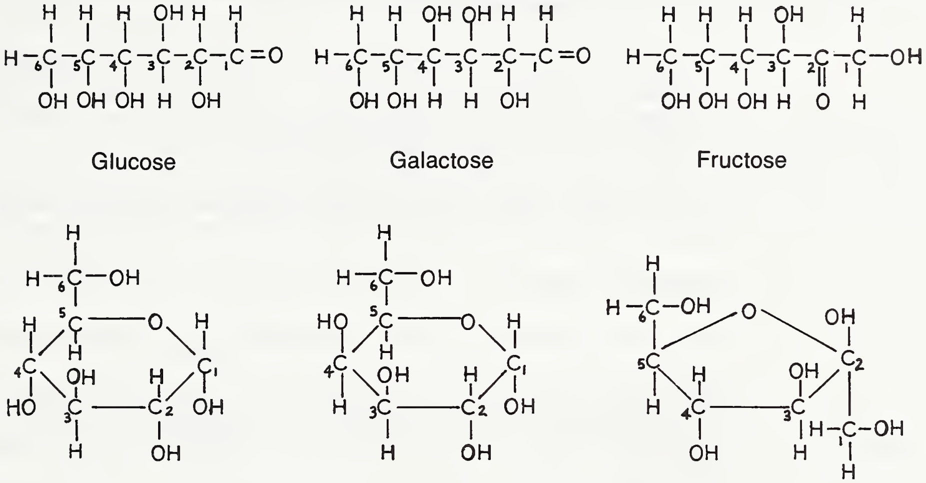
Figure 8: The dehydration synthesis of maltose from two molecules of glucose.

Disaccharides

In the cells of certain plants two units of simple sugars join to form a **double sugar** or **disaccharide**. In order to accomplish this joining a chemical process called dehydration synthesis takes place. During **dehydration synthesis**, a molecule of water is removed to accomplish the end result. **Malt sugar** or **maltose**, a disaccharide, is formed by the joining of two glucose **molecules**. Another example of a double sugar is **sucrose** or cane sugar (known as common table sugar) is produced by sugar cane or beet sugar. **Lactose** or milk sugar is also a double sugar. It is a combination of a molecule of glucose and a molecule of galactose.

You may recall that disaccharides can be separated into their primary components by adding water. The breakdown process is accomplished by hydrolysis or digestion. Hydrolysis involves the splitting of a molecule by adding water. A sucrose molecule for example, may be hydrolyzed into its primary components of glucose and fructose.

Structural Formulas of Three Monosaccharides



Glucose Galactose Fructose

Figure 9: Structural formulas of three monosaccharides. Note that all three molecules have the same numbers of carbon, hydrogen, and oxygen atoms. Their properties are different because in each molecule the arrangement of the atoms is different. Both chain and ring forms are shown.

Polysaccharides

The starches are complex carbohydrates made up of glucose units in long chains. Starch, an example of a **polysaccharide** (pah-lee-sack-uh-ride), comes in many different forms. These forms include potato starch, corn starch, starches in grain such as rice and wheat, and tapioca starch. Glycogen or animal starch is produced in the liver and stored in the liver or in muscles. The liver stores glycogen for future use as an energy source.

Cellulose

Another example of a polysaccharide is **cellulose**. Cellulose is a complex polysaccharide found in the cell walls of plant cells. The component units of cellulose are glucose molecules bonded together side by side. The arrangement of the molecules in cellulose bestows great strength on the cellulose fibres. In terms of function, cellulose provide support in plant cells. This support enables woody plants to grow to enormous heights. Cellulose is often eaten by man. It is not soluble in water and as a rule lacks the sweetness of monosaccharides and disaccharides.

Man does not possess the appropriate enzymes to digest cellulose. When ingested as food materials, for example, raw vegetables and salads, cellulose serves as roughage.

The Lipids

Lipids comprise another group of compounds that are vital to humans. Most lipids are not soluble in water. The most abundant lipids include **fats, oils** and **waxes**. Research scientists have discovered that a given quantity of fat, by weight, contains more energy than an equivalent amount of carbohydrate.

Each fat molecule consists of one molecule of **glycerol** which combines with three molecules of **fatty acids**.

The formation of a fat molecule takes place through **dehydration synthesis**. As the complex fat molecule is formed, three molecules of water are released, one from each molecule of fatty acid. You may be aware that during the process of fat digestion, the reverse of dehydration synthesis, namely, **hydrolysis** occurs.

During hydrolysis water molecules are added to a fat molecule. This breaks the molecule up into three molecules of fatty acids and one molecule of glycerol.

Sources of Lipids

Fats: The chief source of fats is animal tissues. Some fats do appear in milk as butterfat.

Oils: Oils are lipids that remain liquid at room temperature. Sources of oils utilized as food by humans include soybean (soybean oil), cotton seed (cotton seed oil), peanut (peanut oil), corn (corn oil) and olive oil. Please note that all the oils mentioned above are of vegetable origin.

Dehydration Synthesis

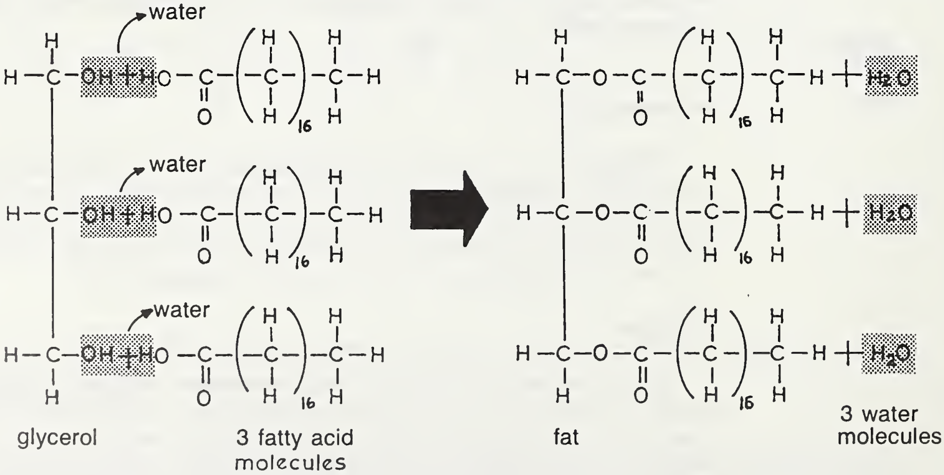


Figure 10: Dehydration Synthesis. The dehydration synthesis of a molecule of fat. Three fatty acid molecules combine with a molecule of glycerol, and yield the fat molecule and three molecules of water.

Waxes

You may be aware that many fruits are naturally covered with waxes and so are many leaves. Apples are coated with wax. Waxes such as those mentioned above and beeswax are closely related to fats.

Normally included among the lipids are a group of fat related substances called sterols. Cholesterol and ergesterol (found in certain foods and in the human skin) are examples of sterols.

Proteins

The most abundant organic compound in living animal cells is protein. In the human body protein may occur in a variety of forms. For example, all structures such as mitochondria, ribosomes and spindle fibres in the cytoplasm of human body cells contain proteins. Biological catalysts (enzymes) which affect the rates of chemical reactions in cells are actually proteins.

Dehydration Synthesis of a Dipeptide

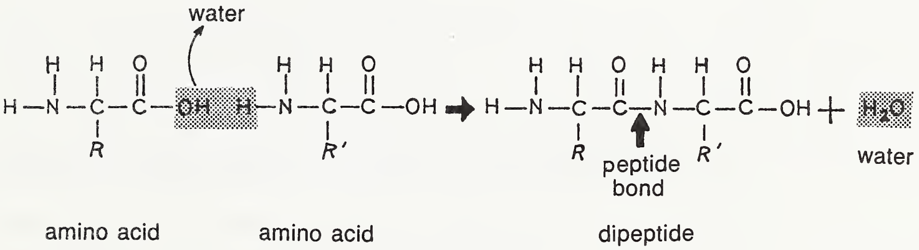


Figure 11: Dehydration synthesis of a dipeptide. As the water molecule is removed, the two amino acid residues become linked by a peptide bond. Long chains of peptides form polypeptides, that compose protein molecules.

Protein also appears in the human body as **keratin**. Keratin is found in the skin, finger nails and toe nails and in hair. A kind of protein called **collagen** is widely distributed in connective tissue and bone.

Another group of proteins found in the body are the antibodies of blood plasma. A very important protein, insulin, is a protein produced in the body by the pancreas. Insulin is one example of a group of proteins called **hormones**. Functionally, insulin and other protein hormones closely regulate the functions of cells and tissues.

Structurally, proteins are made up of units called amino acids. When humans ingest protein foods, these foods are digested into amino acids. Once amino acids are absorbed, they can be assembled into many different kinds of proteins by body cells.

Self-Correcting Exercise 2 (Answers provided)

1. What is an acid?

2. When a base such as sodium hydroxide separates in solution, what are the products?

3. What does a neutral pH signify?

4. Give the pH range for hydrochloric acid in the human stomach following a meal.

5. List two critical factors that affect enzyme action.

6. How would you describe the pH of the environment in which stomach enzymes are at their optimum?

7. Explain the most common approach to naming enzymes.

8. List two important requirements for cells to manufacture and release digestive enzymes.

(a)

(b)

9. List the names of the pairs of salivary glands.

10. What is the initial stimulant in the stomach?

11. Where does the hormone gastrin originate?

12. Where is the target organ or cells for gastrin located?

13. At what point along the digestive tract does pancreatic juice enter the system?

14. Secretin is a hormone. Where does it originate?

15. Identify the source of the hormone cholecystokinin.

16. List three examples of disaccharides.

17. Name the animal starch that is stored in the liver and also in skeletal muscles.

18. Name the carbohydrate which may be consumed by humans but cannot be digested because humans lack the appropriate digestive enzyme.

19. List three categories of lipids.

20. List the components of a fat molecule.

21. What would you consider to be the most abundant compound in living animal tissue?

Check your answers with those provided on pages 42-43. Please make any necessary corrections.

Digestion of Food in the Various Parts of the Digestive Tract

Having completed our summary of the categories of food ingested and utilized by humans we will examine the various digestive processes to which food is subjected.

Digestion of Food in the Mouth

Both the mechanical and chemical aspects of food digestion begin in the mouth of humans. You may recall that humans possess four functional types of teeth which function primarily to crush the solid portions of ingested food in preparation for swallowing and digestion.

Food in the mouth is moistened by the secretion of saliva produced by three pairs of salivary glands. From the salivary glands, saliva is released into the mouth by way of ducts.

As a digestive juice, saliva contains water, an enzyme and mucus. The **mucus** (mucin) is a slippery carbohydrate-protein compound. This compound enables saliva to bind small food particles into small masses which can easily be swallowed. The water in saliva bestows the ability to taste, aids in chemical digestion by dissolving food particles, as well as moistening the food.

Only one kind of food is acted upon in the mouth by the enzyme in saliva. The enzyme, salivary amylase (also called ptyalin) acts as a catalyst in the hydrolysis of starch. Starch is digested, producing maltose as an intermediate end product in starch digestion. The optimum pH for salivary amylase to be effective is 6. In other words the enzyme works best in a slightly acidic environment. Starch digestion is completed later.

The Pharynx (Throat)

As food from the mouth is swallowed, it passes through the pharynx and into the esophagus. Initially, swallowing is under the control of the "will," that is, it is a voluntary action. Once the food passes the upper part of the pharynx, however, swallowing becomes an automatic or reflex action (involuntary). While still in the pharynx, salivary amylase in the saliva, mixed with food, continues its digestive action on starches. No other digestive action, however takes place in the pharynx.

On its way to the stomach, food passes from the pharynx to the esophagus. During this brief journey it comes into contact with the epiglottis. The epiglottis is a flap of tissue that closes the glottis or entrance to the windpipe when food reaches this point. As swallowing proceeds, the epiglottis moves downward, the larynx (voice box) moves upwards and the **glottis** (entrance to the windpipe) closes. All the above mentioned activities serve two purposes; food is prevented from entering the trachea. Secondly, food is directed toward the esophagus. If solid food or liquids accidentally enter the trachea, the food is usually brought up by reflex action resulting in coughing.

The Esophagus (Gullet)

This section of the digestive system connects the pharynx to the stomach.

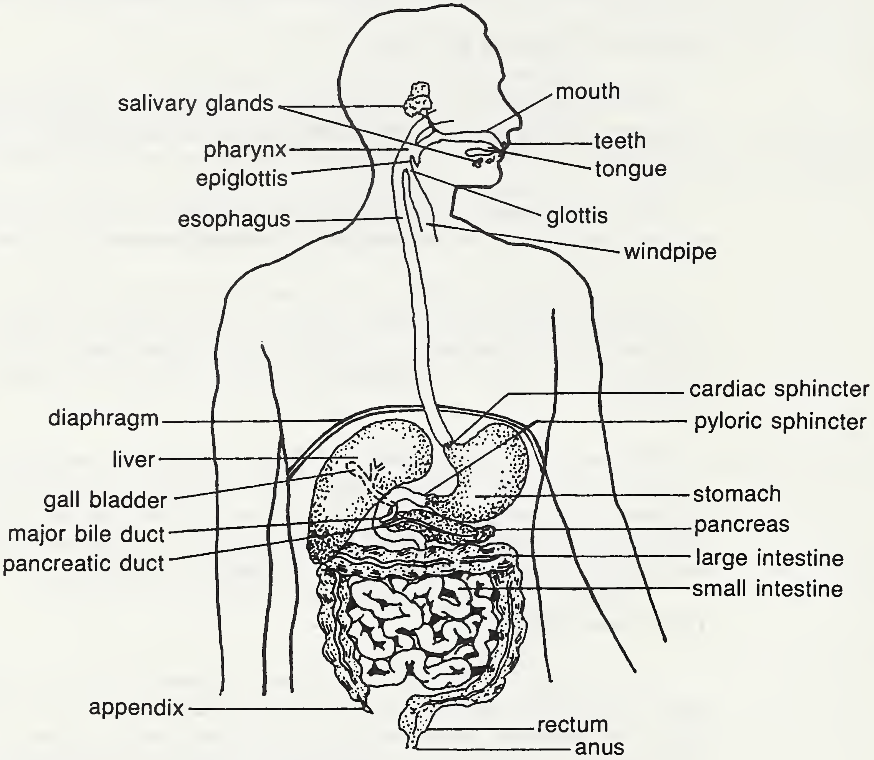


Figure 12: Human digestive system

Glands in the walls of the esophagus secrete mucin which lubricates the passage of food as food travels toward the stomach. Food in the stomach is under automatic control and is propelled downward by a series of rhythmic wave-like muscular contractions and relaxation. These contractions and relaxations called **peristalsis** push the food downward into the stomach.

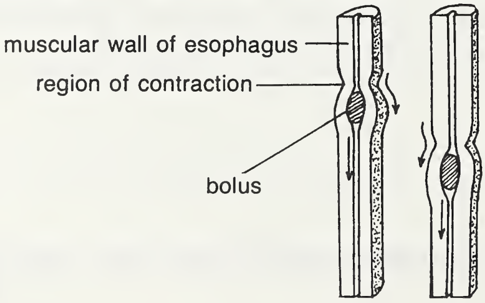


Figure 13: Diagram to illustrate peristalsis

The Stomach

Digestion of food in the stomach may take one to four hours. When food arrives in the stomach it is mixed with secretions from the lining of the stomach. The lining of the stomach contains pits or gastric glands with several kinds of secreting cells. These cells include the **zymogenic, parietal, mucous** and **enteroendocrine** cells. The **zymogenic** cells, perhaps the most important, secrete the **inactive enzyme pepsinogen**. The parietal cells secrete **hydrochloric acid** and an intrinsic factor. The acid converts the inactive **pepsinogen** to the active enzyme **pepsin**. The intrinsic factor assists in the absorption of vitamin B_{12}. The **mucous cells** produce **mucus**. The **enteroendocrine cells** secrete stomach **gastrin**, the hormone which in turn stimulates the secretion of hydrochloric acid and pepsinogen. Collectively the secretions of the stomach are called **gastric juice**. The food in the stomach is thoroughly mixed with gastric juice by waves of peristalsis occurring every 15-25 seconds. The result of the mixing is a soupy mixture called **chyme** (kime). The hydrochloric acid provides the acid environment required by the digestive enzymes present.

Protein digestion begins in the acid environment. The enzyme pepsin reduces proteins to smaller molecules called **peptides. Renin**, the other enzyme in **gastric juice**, present only in the stomach of young mammals, reacts with calcium to clot the protein **casein** in milk. The clotting or coagulation of milk prevents too rapid a movement of milk from the stomach and allows enough time for pepsin to act on them. Pepsin cannot break protein down into its end product, amino acids. That stage of the breakdown takes place later in the small intestine.

Another enzyme present in the stomach is **gastric lipase**. Gastric lipase has been shown to function in the partial splitting of butterfat molecules in milk. The optimum pH established for this enzyme is pH 5.6. The pH in the stomach has been established at pH 1 to 3. The digestion of butterfat and all other fats is completed in the small intestine.

Pepsin and the Walls of the Stomach

Recall that the cells making up the inner lining of the stomach is primarily protein. The protein-digesting enzyme carries out its functions in the stomach but does not digest the stomach itself. The explanation lies in the fact that during digestion and at other times the stomach lining is coated with a layer of mucus which strongly resists digestion by pepsin. Another explanation concerns the presence of pepsin and hydrochloric acid in the stomach. Normally, pepsinogen and hydrochloric acid are released by the stomach lining only after protein food enters the stomach. It follows then, that pepsin and hydrochloric acid are not normally present in the stomach unless protein food is ingested.

Occasionally, however, the natural barriers of the stomach break down and a sore or inflammation called an **ulcer** develops.

Digestion in the Small Intestine

Chyme, the liquified food from the stomach passes through the pyloric sphincter and enters the duodenum, the first part of the small intestine. Food moves into and along the small intestine by peristalsis. The digestive processes commenced in the mouth and stomach are completed in the small intestine. The completion of this digestive process in the small intestine is dependent upon the secretions from three glands. These glands include the **liver,** the **pancreas** and the **intestinal glands**. Both the liver and pancreas empty their secretions through ducts into the duodenum. The pancreas produces pancreatic (pan-kree-at-ic) juice; the liver produces bile and the intestine produces intestinal juice.

The Liver

Within the liver bile is produced and stored in the **gallbladder**. When food is present in the duodenum, bile is released from the gallbladder through ducts and transported into the duodenum. Bile varies in color from yellow to green. Although it contains no digestive enzymes, bile is considered to be a digestive juice. Its contents include **water, bile salts** and **bile pigments**. Bile salts help to reduce the surface tension of fat, thus facilitating more rapid digestion. The action of bile, as an **emulsifier**, breaks fat and oils into small droplets. The droplets remain in solution in the fluid food mass. Emulsification is a physical process and emulsified fat mixes readily with water and the resulting fluid is called an **emulsion**. Emulsified fats are ready for chemical breakdown by the enzyme **lipase** in **pancreatic juice**. Besides acting as an emulsifier bile promotes peristalsis and increases the solubility of vitamins to facilitate rapid absorption.

The removal of the gallbladder by surgery does not pose any major problems for fat digestion. The liver continues to produce bile after removal of the gallbladder. Some of this bile is still stored in the bile ducts and released when required. However, with less bile present, less fat is digested. This results in a large portion of the fats ingested, being released as undigested materials through the digestive tract. Bile salts also serve to change the pH of the food (chyme) entering the small intestine from slightly acidic to slightly basic or alkaline.

The Pancreas and Its Role in Digestion

The pancreas can be observed as an elongated whitish gland measuring about 30 cm in length. It is located within the loop formed by the duodenum. It is located just beneath the surface of the stomach.

The gland contains two kinds of **secretory tissues**. One kind is distributed as isolated patches throughout the organ. This tissue secretes hormones. The patches, called **Islets of Langerhans**, account for about one percent of the pancreatic cells. These are referred to as **endocrine cells** and consists of **alpha, beta** and **delta** cells. Three hormones are produced and secreted by the Islets of Langerhans, namely **glucagon, insulin** and **somatostatin.**

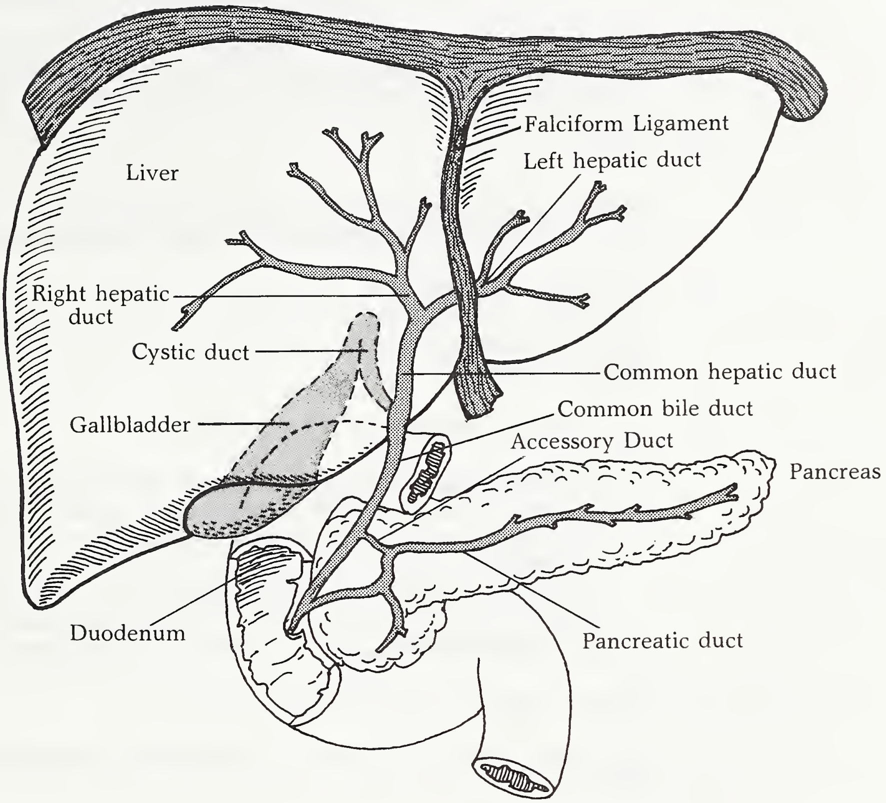


Figure 14: Pancreas. Relations to liver, gallbladder and duodenum

The greater portion of the pancreatic tissues secrete pancreatic juice. This secretion is emptied into the duodenum by the pancreatic duct. Chemical analysis of pancreatic juice shows a composition of **sodium bicarbonate,** an **amylase,** a **lipase**, two **proteinases**, a **carbopeptidase** and **nucleases**.

(a) Sodium Bicarbonate ($NaHCO_3$)

The primary function of sodium bicarbonate is to neutralize the acidity of the newly arrived contents of the small intestine. The pH is rapidly raised to about pH 8. This pH has been shown to be about the optimum for most pancreatic enzymes.

(b) Amylase

Pancreatic amylase continues the process of starch digestion commenced in the mouth. In the small intestine **pancreatic amylase hydrolizes starch into maltose.**

(c) Lipase (also called **steapsin** - a fat digesting enzyme)

In the small intestine pancreatic lipase breaks down fat and oil into glycerol and fatty acid molecules.

(d) Two Proteinases (Proteases or Proteinases)

(i) **Trypsin**: This protein-digesting enzyme is one of the major proteinases. This enzyme continues the digestion of proteins commenced in the stomach by the enzyme **pepsin**. The pancreas releases trypsin in its inactive form **trypsinogen**. For the conversion of inactive trypsinogen to active trypsin the action of another enzyme enterokinase is needed. **Enterokinase** is normally present in intestinal juice. Trypsin digests protein into **dipeptides** and **polypeptides** (also called **proteoses** and **peptones**).

(e) Carbopeptidase (a protein-digesting enzyme)

This enzyme functions in the digestion of **peptides** and **polypeptides** into **amino acids**.

(f) Nucleases (digest RNA and DNA)

The principal nucleic acid digesting enzymes in the body of the human adult are called respectively **ribonuclease** and **deoxyribonuclease.**

Self-Correcting Exercise 3 (Answers provided)

1. What is mucin?

2. What is the digestive function of salivary amylase?

3. What digestive action takes place in the pharynx?

4. List the secretory cells located in the gastric glands.

5. Identify the location where the enzyme pepsinogen enters the digestive tract.

6. List two proteinases present in the stomach of young mammals (eg. humans).

7. Give two explanations for the walls of the stomach to remain intact despite the strong acid environment.

   (a) ____________________

   ____

   ____

   ____

   (b) ____________________

   ____

   ____

   ____

8. Into what section of the digestive tract do the liver and pancreas empty their secretions?

   ____

   ____

9. List the three secretions of the pancreas?

   (a) ____________________

   (b) ____________________

   (c) ____________________

10. What is the primary function of sodium bicarbonate in the small intestine?

    ____

    ____

    ____

Check your answers with those on pages 43-44. Make the necessary corrections.

Intestinal Glands (Digestion in the Small Intestine)

The structure of the small intestine is especially adapted for its functions. For example, the **mucosa** or **lining** of the small intestine is covered with a series of villi. Each villus projects about 0.5 - 1 mm high. This gives the intestinal mucosa its velvety appearance. Estimates indicate that there are four to five million villi along the mucosa of the small intestine. These villi significantly increase the surface area of the epithelium available for digestion and absorption.

When microscopically examined, each villus is seen to have embedded in it, an **arteriole**, a **venule**, a **capillary network** and a **lacteal** or **lymphatic vessel**.

Digested food that diffuse through the epithelial cells covering the villi are able to pass through the walls of the capillaries and the lacteal to enter the blood circulatory system and the lymphatic system.

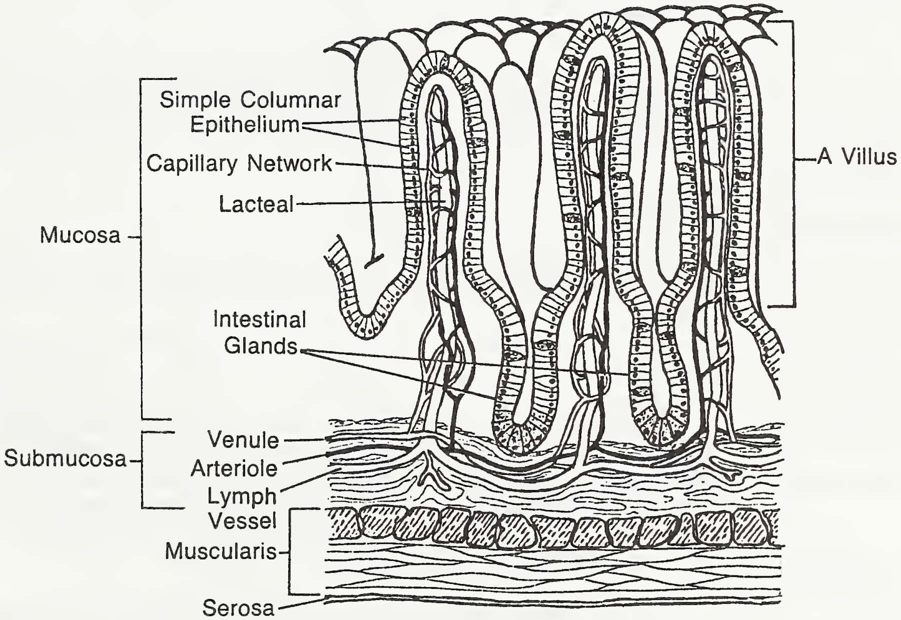


Figure 15: Intestinal Villi, Lymphatic System

Enzymes in the Small Intestine

A series of digestive enzymes produced and secreted by glands located in the mucosa of the small intestine completes the digestion of food, a process which was commenced in the mouth. The secretions of the intestinal glands are collectively called **intestinal juice**. Intestinal juice has been shown to be slightly alkaline, about ph 7.3.

Other cells in the lining of the small intestine secrete additional mucus. This mucus lines and protects the intestines from the direct effects of the digestive enzymes. The mucus also helps to lubricate the food enhancing its easy passage along the intestinal tract. Recall that the cells which make the protein-digesting enzymes avoid being digested by these very digestive enzymes. Because the enzymes are manufactured in an inactive form they cannot function until they reach the digestive tract where they are activated by chemicals present there. Earlier in this lesson we discussed inactive enzymes such as pepsinogen and trypsinogen.

The digestive process started in the mouth is finally completed in the small intestine. In the small intestine the liquified material containing the intermediate and end products of digestion is called **chyle**. The products of digestion contained in chyle include glucose - the end product of carbohydrate digestion; **amino acids** , the end product of protein digestion; **fatty acids** and **glycerol**, the end products from fat and oil digestion and nucleotides from the digestion of RNA and DNA.

Peptidases

The peptidases in the small intestine digest the partly digested protein (polypeptides and dipeptides) into their component amino acids, pentoses and nitrogenous bases. The protein digesting enzymes at work at this stage of digestion include amino-peptidase, dipeptidase, ribonuclease and deoxyribonuclease.

Lipase

Pancreatic lipase, an enzyme in pancreatic juice, digests about one-third of the fats into fatty acids and monoglycerides. The digestion of fats and oils is completed in the small intestine.

Disaccharidases

Three types of disaccharidases are found in the intestinal juice. These enzymes digest the disaccharides maltose , sucrose and lactose. The enzyme **maltase** digests the disaccharide **maltose** into **two glucose molecules**. The end product of starch digestion is glucose. Here, in the small intestine also, the enzyme **sucrase** digests **sucrose** (table sugar) into one molecule of **glucose** and one of **fructose**. The enzyme lactase digests lactose (milk-sugar) into one molecule of **glucose** and one molecule of **galactose**.

With the action of the enzymes mentioned, the digestion of carbohydrates, proteins and fats and oils is completed in the small intestine. Finally, the original large molecules of food ingested have been reduced to small molecules immediately available for passage (absorption) into the bloodstream and the lacteals.

Summary - Action of Digestive Enzymes on Nutrients

Region of Digestive Tract	Digestive Gland	Digestive Juice Produced	Enzyme in Juice	Substances Acted Upon	Intermediate Products	End Products
Mouth	Salivary Glands	Saliva	Salivary Amylase	Starch	Maltose	
Stomach	Gastric Glands (in stomach lining	Gastric Juices	Pepsin	Protein	Peptides and Polypeptides	
			Renin	Milk Protein	Clots Casein (Milk Protein)	
Duodenum	Pancreas	Pancreatic juice	Trypsin (Protease)	Proteins and Peptides	Polypeptides	Amino Acids
			Amylopsin (amylase)	Starch	Maltose	
			Steapsin (lipase)	Fats and Oils	Emulsified lipids	Fatty acids and Glycerol
			Nuclease	Nucleic Acids	Nucleic Acids	Nucleotides
	Liver	Bile		Fats and Oils	Emulsified Fats	
Ileum	Glands in the lining of the small intestine (between the villi)	Intestinal Juice	Maltase	Maltose		Glucose
			Sucrase	Sucrose		Glucose and Fructose
			Peptidase	Polypeptides and peptides		Amino Acids
			Lactase	Lactose		Glucose and Galactose
			Lipase	Emulsified Fats		Fatty Acids and Glycerol
Colon						

Absorption of the End Products

The end products of digestion present in the small intestines are absorbed into the bloodstream and the lacteals. These products are transported to every cell in the human body where they are eventually utilized. The undigested and indigestible material remaining in the small intestine is moved by peristalsis into the colon or large intestine.

Recall that all the chemical and mechanical phases of digestion occurring from the mouth to the small intestine contributed to the reduction of foods to end products that can easily pass into blood and lymph vessels. These end products include **monosaccharides** (glucose, fructose and galactose), **amino acids** and **fatty acids,** and **glycerol (glycerides)**. The passage of these digested nutrients from the digestive tract into the blood or lymph constitutes **absorption**.

In terms of proportion, about **ninety percent** of all nutrients are absorbed throughout the length of the small intestine. The remaining **ten percent** of absorption occurs in the stomach and large intestine.

Although not completely understood, scientists have discovered that the process of absorption occurring in the small intestine occurs specifically through the **villi**. Absorption depends on physical processes such as **diffusion**, a kind of **facilitated diffusion, osmosis** and the process of **active transport**. Whatever the mechanism utilized for absorption, the speed of the process is significantly increased many times because of the structure of the mucosal surface of the small intestine. The villi increase the surface area available for the absorption of the digested material.

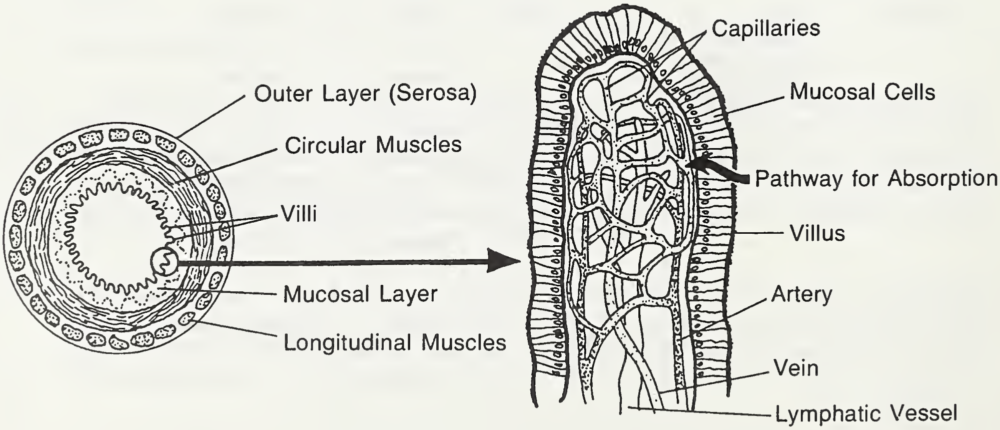


Figure 16: Cross section of mucosal lining of the small intestine. Mucosal cells form the inner lining of the small intestine (cross-section at top). These cells are specialized to absorb digested foods and provide the pathway for food to enter the blood circulation.

Before the nutrient-rich blood reaches the general circulation it passes through the liver. The molecules of digested food from the intestine enter the bloodstream and lymph vessels. From there these food nutrients enter the blood capillaries of the villi and are carried away. These capillaries unite to form veins and eventually join up to form one large vein, the **hepatic portal vein**.

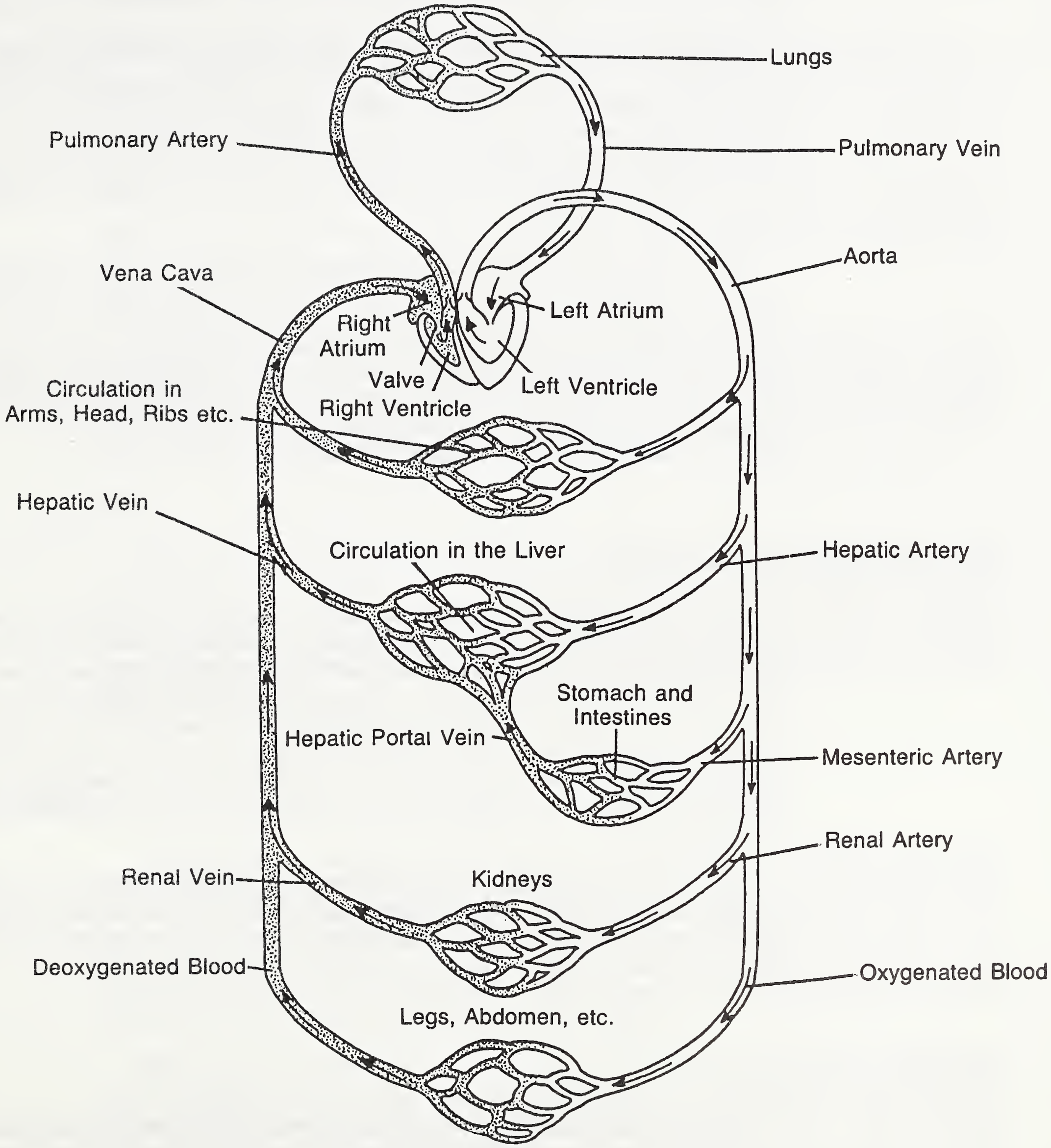


Figure 17: Diagram of human circulation

This vein transports all the blood loaded with food nutrients picked up in the intestine, to the liver. The liver may retain or alter any of the products contained in the blood. Here the liver plays the significant role of screening the blood that is delivered to it. From the liver the digested food reaches the general circulation to be transported to every cell in the body. It is important to recall that the result of having blood pass through the liver, is that blood composition, as it leaves the liver, is the normal composition for that organism.

From the liver a portion of the amino acids and some glucose are distributed by the blood to other parts of the body where they are needed. The greater quantity of amino acids and glucose are retained in the liver upon arrival. Researchers have been able to demonstrate that all monosaccharides with the exception of glucose (e.g. fructose and galactose) entering the liver are converted to glycogen. Any glucose in excess of the normal 0.1% concentration found in the blood is converted by the liver into the insoluble polysaccharide **glycogen** for storage as animal starch.

Some of the amino acids that enter the liver are released and utilized by body cells and tissues for growth, maintenance and repairs. All amino acids in excess of the body's needs are deaminated by the liver. The process of deamination involves the removal of an NH_2 (nitrogen-containing group) from the amino acid molecule. The amino group is toxic to animals and must be removed. Upon removal the amino group is combined with **carbon dioxide** (CO_2) to form urea. **Urea** is then excreted in **urine**. The remaining portion(residue) of the amino acid molecule is ready for entry into the metabolic pathway of cellular respiration. In the metabolic pathway it is oxidized for energy.

Fatty Acids, Glycerol and Glycerides

Based on the results of continuing research work, scientists are able to conclude that fatty acids, glycerol and glycerides resulting from the digestion of fat and oils are absorbed into the body under varying conditions and at different locations. For example, only a portion of the end products from the digestion of fat and oils enter the capillaries of the villi. These molecules are normally too large. Experimental evidence suggests that a large proportion of these products may be recombined in the villi to form fat once again and then the fats pass into the **lacteals**. Furthermore, there is evidence that some of the finely emulsified fat is absorbed directly (without digestion) and eventually enter the lacteals, the normal surface for fat absorption.

Because of their large size, molecules of fatty acids and glycerol cannot be absorbed into the capillaries, hence they are absorbed into the lacteals. From the lacteals the fat-containing fluid enters the lymphatic system. The lymphatic system returns lymph (interstitial fluid), to the circulatory system.

Other Dietary Requirements

Besides carbohydrates, fats and proteins, the body requires other materials and nutrients for proper functioning and overall good health. Let us consider briefly, three of these nutrients.

Mineral Salts

Mineral salts are inorganic compounds which are essential for proper formation and functioning of body parts. These salts combine with other food components in order for the components to carry out their functions. Here is a list of some mineral salts and their dietary function:

Sodium (a component of common table salt) essential for regulating blood pressure.

Potassium (present in certain fruits such as bananas) is necessary for proper functioning of nerves and muscles.

Calcium (obtained from milk and dairy products) is essential for building bones and teeth.

Iron (obtained from meat and certain vegetables) is a vital component of red blood cells.

Vitamins

These are a group of substances important in the human diet. They are organic, are of plant origin and are utilized in regulating body functions. Under most conditions vitamins cannot be synthesized by the human body and hence must be ingested as part of a balanced diet. Prolonged vitamin deficiencies manifest themselves as the cause(s) of certain diseases. Many of these diseases, if not corrected, lead to death.

Water

Although not considered a food substance or mineral, water is a vital inorganic substance in the diet. In the human body, water acts as the solvent for all body fluids. As a solvent, its functions are numerous. It dissolves most substances for transportation and absorption. Water is indispensable with regard to the removal of body wastes, the regulation of body temperature, and the chemical synthesis of proteins and other compounds. It is also needed to aid food digestion.

The Large Intestine

Undigested and unabsorbed materials left in the small intestine is passed on to the large intestine. Materials entering the large intestine normally lack the nutrient end products of digestion. This lack of nutrients is due to the fact that most nutrients have already been absorbed into the bloodstream through the villi of the small intestine. The contents of the large intestine consists of water, undigested cellulose and vegetable fibres. These primarily undigested and indigestible materials also contain bacteria, mucus and dead cells from the digestive tract. The amount of water present is significant.

While the large intestine does not secrete any digestive enzymes, it does secrete mucus which functions as a lubricant and also protects the intestinal linings from still active enzymes which may have entered with the undigested material. The nutrients we are unable to digest end up in the large intestine supporting the growth and multiplication of large amounts of bacteria. For the most part these bacteria, primarily the common species, **Escherichia coli** are harmless. The extent of the bacterial content of the large intestine is such that estimates are that from 10% to 50% of the dry weight of feces is bacteria. Many of the bacteria located in the large intestine are useful. They synthesize for humans substances required by the body such as vitamin K and vitamin B_{12}. These useful materials are then absorbed.

Occasionally harmful bacteria and some protozoans may become established in the large intestine. Sometimes the micro-organisms of the large intestine cause diseases such as amoebic dysentry, typhoid fever and Asiatic cholera. You may recall that the major functions of the large intestine are absorption and egestion. The process of absorption involves reclamation of water that is secreted into the stomach and intestine by the various digestive glands. If all this water was lost, the individual would suffer thirst and dehydration. Occasionally, the large intestine becomes irritated. As a result it discharges its contents into the rectum and out the anus before the reabsorption of water has been completed. This rapid release of contents is called **diarrhea.** If on the other hand, under certain conditions, the large intestine may retain its contents too long. The result is often a drying out of the fecal material resulting in the condition known as **constipation.**

Uptake of Foreign Substances

There are about 70,000 chemicals in commercial use today and several hundred new ones are introduced each year. Many of these chemicals are either added directly or indirectly to the food we eat. Indirectly, pesticides, herbicides and fungicides often are found on fruit and vegetables. Some 2,000 materials are often added to our food products to enhance consumer acceptability. Food additives include things such as dietary supplements, flavors, acidifiers, alkalizers, buffers, sweeteners, stabilizers, thickeners, emulsifiers, preservatives and antigerm agents.

All food in the natural state are complex mixtures of chemical compounds. Our digestive systems sole function is to break down and absorb chemical compounds for use at the cellular level. Those chemicals which are a certain size or have certain chemical properties are quickly absorbed into the circulatory system and distributed throughout the body. Not all of these substances are nutrients like amino acids or simple sugars. Some of these substances could be called **foreign substances**. These chemicals are not useful or necessary for any life function. Examples of foreign substances could include alcohol, mercury, lead, arsenic, pesticides (DDT) and herbicides.

Some of the foreign substances which are absorbed can be readily broken down by the liver and excreted from the body. Ethyl alcohol is a good example of a substance which is absorbed into the bloodstream and has temporary effects. The liver is able to break down this type of alcohol and eliminate it. This is why we do not remain intoxicated forever after drinking a large amount of alcohol.

Unfortunately not all substances absorbed are easily broken down or excreted. Heavy metals, like mercury, lead, arsenic and pesticides like DDT accumulate in various tissues. Low levels of these substances may have no real effect on our health but high concentrations can cause damage to cells, cell membranes and metabolic processes, leading to illness and eventually death. It has been estimated that 80% to 90% of all cancers are caused by chemical compounds in the environment.

Disorders of the Digestive Tract

Homeostatic disorders of the digestive tract do develop from time to time. Some are more serious than others. Some of the disorders may be attributed to **lifestyle** or to **abnormal diets**.

Peritonitis

This disorder refers to an acute inflammation of the lining of the body cavity and large and small intestine. This malfunction is mentioned here because one probable cause could be bacterial entry from the large intestine. If intestinal bacterial enter the peritoneum lining of the body cavity as they attack the cells of the peritoneum for food, they produce acute infection. If for some reason there is a perforation through the wall of the digestive tract, bacteria could escape and attack not only the peritoneum but also other vital organs of the body. Patients scheduled for extensive surgery on the colon may be given high doses of antibiotics for several days prior to the surgery in order to destroy intestinal bacteria, thereby reducing the risk of contamination of the peritoneum.

Ulcers

An ulcer is a sore, inflammation or crater-like damage in a membrane of the body. Ulcers are named according to where they appear in the digestive tract. If the ulcer appears in the areas exposed to **acid gastric juice**, they are called **peptic ulcers**. Peptic ulcers sometimes develop in the lower end of the esophagus. Statistics show that most ulcers occur on the lesser curvature of the stomach or in the first part of the duodenum. If located on the lesser curvature of the stomach they are called **gastric ulcers**. If they are located in the first part of the duodenum, they are **duodenal ulcers.**

The immediate cause of duodenal ulcers is believed to be over-secretion of acidic, gastric juice. In patients with stomach ulcers, however, the immediate cause of the ulcer is believed to be under-secretion of mucus which normally protects the walls of the stomach from the effects of acid gastric juice. There is evidence also that excessive secretion of pepsinogen (later becomes active pepsin) may contribute to the development of gastric ulcers.

Several factors are believed to stimulate excess acid secretion in the stomach. These factors include emotions, foods such as coffee, spices, alcohol and medication such as aspirin.

Gallstones

Surgical removal of the gallbladder (cholecystectomy) is a rather frequently performed operation. Bile is continually produced by the liver, but between meals the bile is stored in the gallbladder.

You may recall that as food enters the duodenum, a hormone (cholecystokinin) is released. This hormone stimulates the gallbladder to release its contents through the bile duct into the duodenum. Sometimes the cholesterol in bile crystalizes and precipitates forming small gallstones. The gallstones partly block the flow of bile. Other substances including dead bacteria may increase the size of the gallstones. When the gallbladder is unable to empty as it normally does following a meal, the pressure within it increases resulting in severe pain. This pain may be felt as far away as the lower back or in the right shoulder. Death can result from the complete obstruction of the flow of bile to the duodenum.

Appendicitis

Appendicitis is an inflammation of the appendix. The inflammation is usually preceeded by an obstruction of the lumen (space within) of the appendix. The lumen may be obstructed by a variety of conditions and substances. These include inflammation, kinking of the appendix, cancer of the cecum, a foreign substance such as small seeds (e.g. tomato seeds), residues or fecal material.

Sometimes an initial inflammation of the appendix spread throughout the organ. The fully inflamed appendix may result in edema or gangrene. If an inflamed appendix ruptures, releasing bacteria into the abdominal cavity, peritonitis may result. Following diagnosis, an inflamed appendix is usually surgically removed early in order to reduce the risk of gangrene, rupture and peritonitis. The incision is usually made through the muscle layers of the right lower abdominal wall.

Self-Correcting Exercise 4 (Answers provided)

1. List four components of a villus.

(a) ____________________

(b) ____________________

(c) ____________________

(d) ____________________

2. Compare the pH of intestinal juice and that of gastric juice.

3. List the products of digestion found in chyle.

(a) ____________________

(b) ____________________

(c) ____________________

(d) ____________________

4. List three categories of digestive enzymes present in the small intestine.

   (a) ____________________

   (b) ____________________

   (c) ____________________

5. What constitutes absorption?

6. List four different cellular processes by which absorption can occur.

   (a) ____________________

   (b) ____________________

   (c) ____________________

   (d) ____________________

7. Name the blood vessel that delivers to the liver, blood loaded with nutrients absorbed from the lining of the intestine.

8. The screening process for blood prior to its release into the general circulation takes place in a particular gland. Name the gland.

9. What is the normal concentration of glucose in human blood?

10. What is deamination?

11. What is urea composed of?

12. List four examples of mineral salts required by the human body.

(a)

(b)

(c)

(d)

13. List five processes or activities in the body for which water is indispensable.

(a)

(b)

(c)

(d)

(e)

14. List two useful products produced by bacteria in the large intestine.

(a)

(b)

15. List four fairly common disorders of the digestive tract.

(a) ______________________________

(b) ______________________________

(c) ______________________________

(d) ______________________________

Check your answers with those on pages 44-45. Please do the necessary corrections.

ANSWERS TO EXERCISES

Exercise 1

1. By combining the chemicals in food with oxygen.

2. (a) Food is prepared for swallowing.
   (b) Increases the surface area of the food to be digested.

3. A wavelike series of contractions of the longitudinal and circular muscles in the walls of the digestive tract.

4. (a) Takes place after the food has been engulfed by the cell.
   (b) Digestive enzymes are secreted from the cell. The food is digested outside the cell.

5. (a) vitamins
   (b) mineral salts
   N.B. except water

6. An enzyme.

7. Compounds upon which enzymes act.

8. The optimum temperature.

9. Proteins

10. Body temperature 37°C

Exercise 2

1. A substance that releases or donates hydrogen ions (H^+) in solution.

2. Na^+ and OH^- or Sodium ion and Hydroxyl ion

3. That the substance is neither acidic nor basic.

4. pH 1 to 3

5. pH and temperature

6. Acidic

7. Take the prefix of the substrate molecule and add to it the suffix "-ase" (e.g. protein + ase = proteinase)

8. (a) Hormonal stimulation
   (b) Nervous stimulation

ANSWERS TO EXERCISES (contd)

Exercise 2

9. Sublingual
   Submaxillary
   Parotid

10. Undigested food

11. The walls of the stomach

12. In the wall of the stomach

13. At the duodenum

14. In the duodenum

15. The small intestine

16. (a) maltose
    (b) sucrose
    (c) lactose

17. Glycogen

18. Cellulose

19. Fats
    Oils
    Waxes

20. One molecule of glycerol, three molecules of fatty acid

21. protein

Exercise 3

1. A slippery carbohydrate-protein compound found in saliva and along the digestive tract.

2. Salivary amylase catalyses the breakdown of starch to maltose.

3. The breakdown of starch by salivary amylase continues in the pharynx.

4. zymogenic
   parietal
   mucous
   enteroendocrine

ANSWERS TO EXERCISES (contd)

EXERCISE 3

5. the stomach

6. (a) pepsin
   (b) renin

7. (a) Pepsinogen and hydrochloric acid are present in the stomach only after protein food enters.
   (b) During digestion and at other times the stomach lining is coated with a layer of mucus which strongly resists digestion by pepsin.

8. the duodenum

9. any three of: insulin, glucagon, pancreatic juice, sodium bicarbonate, an amylase, lipase, proteinase.

10. To neutralize the newly arrived contents from the stomach, within the small intestine.

Exercise 4

1. (a) an arteriole
   (b) a venule
   (c) a capillary network
   (d) a lacteal

2. (a) intestinal juice pH 7.3
   (b) gastric juice pH 1-3 range

3. (a) glucose
   (b) amino acids
   (c) fatty acids and glycerol
   (d) nucleotides

4. (a) peptidase
   (b) lipase
   (c) disaccharidase

5. The passage of digested nutrients from the digestive tract into the blood or lymph by way of the villi of the small intestine.

6. (a) diffusion
   (b) osmosis
   (c) active transport
   (d) facilitated diffusion

7. the hepatic portal vein

8. the liver

9. 0.1%

10. Removal of the toxic (NH_2) amino group from each amino acid molecule

11. (a) carbon dioxide
    (b) an amino (NH_2) group

12. (a) potassium
    (b) calcium
    (c) sodium
    (d) iron

13. (a) removal of waste
    (b) temperature regulation
    (c) absorption
    (d) transportation
    (e) chemical synthesis

14. (a) vitamin K
    (b) vitamin B_{12}

15. (a) gallstones
    (b) ulcers
    (c) peritonitis
    (d) appendicitis

EXERCISES TO BE SUBMITTED FOR CORRECTION AND GRADING

Select the best answer or answers to each question.

______ 1. Which of the following is **not** a component of pancreatic juice?

(a) sodium bicarbonate
(b) an amylase
(c) proteinases
(d) bile salts

______ 2. Which of the following has no direct effect on the absorption of the end products of digestion in the small intestine?

(a) diffusion
(b) osmosis
(c) capillarity
(d) active transport

______ 3. Which of the following would **not** be a condition or substance to cause an inflamed or ruptured appendix?

(a) kinking of the structure itself
(b) a foreign substance obstructing the lumen of the appendix
(c) inflammation
(d) hyper-secretion of bile

______ 4. Which of the following is not a likely immediate cause of duodenal gastric ulcers or peptic ulcers?

(a) over-secretion of acid gastric juice
(b) under-secretion of mucus
(c) over-secretion of pepsinogen
(d) over-secretion of phyalin (salivary amylase)

______ 5. Food is lubricated in the mouth by the substance in saliva called

(a) citric acid
(b) amylase
(c) mucin
(d) bile salts

______ 6. The part of the digestive system in which a digestive juice is not secreted is the

(a) mouth
(b) esophagus
(c) stomach
(d) small intestine

______ 7. In the stomach, proteins are partially digested into

(a) emulsified fats
(b) proteases
(c) peptides
(d) glucose

______ 8. The chemical digestion of food becomes more effective when mechanical digestion

(a) increases the surface area of the food
(b) increases the pH of the food
(c) increases the volume of the food
(d) decreases the surface area of the food

______ 9. Nutrient molecules in the digestive tract are made simpler by means of organic catalysts called

(a) hormones
(b) molars
(c) solutes
(d) enzymes

______ 10. Cane and beet table sugar are examples of

(a) sucrose
(b) maltose
(c) glucose
(d) lactose

______ 11. Which organ is **not** considered to be part of the digestive system?

(a) pancreas
(b) spleen
(c) liver
(d) esophagus

______ 12. The surgical removal of the gallbladder would interrupt the normal flow of

(a) cholesterol
(b) bile
(c) blood
(d) gastric juice

______ 13. A digestive juice that lacks enzymes is

(a) intestinal juice
(b) saliva
(c) pancreatic juice
(d) bile

______ 14. The emulsification of fats and oils results from the action of

(a) bile
(b) pancreatic juice
(c) enzymes
(d) gastric juice

______ 15. A carbohydrate that must be hydrolyzed to be used by the cells is

(a) glucose
(b) fructose
(c) galactose
(d) sucrose

______ 16. Material in the large intestine lacks most of the end products of digestion because the end products have already been absorbed in the

(a) esophagus
(b) stomach
(c) small intestine
(d) gall bladder

______ 17. The end products of protein digestion are

(a) fatty acids
(b) amino acids
(c) glucose
(d) glycerol

______ 18. Fats are digested by means of enzymes called

(a) amylases
(b) proteases
(c) peptidases
(d) lipases

______ 19. Contraction of the gallbladder is best described as being under which type of control?

(a) hormonal
(b) nervous
(c) mechanical
(d) voluntary

______ 20. Which of the following represents the end product of carbohydrate digestion?

(a) monosaccharide
(b) disaccharide
(c) cellulose
(d) polysaccharide

______ 21. Which of the following is **not true** of enzymes in living systems?

(a) Enzyme effectiveness is critically affected by pH
(b) The critical effect of heat on enzyme activity is a factor in determining where certain animals may live
(c) Enzymes are protein in nature
(d) Enzymes are totally used up by the chemical reaction they catalyze

______ 22. Enzymes alter the rate of a reaction by

(a) decreasing the activation energy
(b) increasing the activation energy
(c) decreasing the amount of substrate
(d) increasing the amount of substrate

Circle your choice, True or False.

T F 23. Bile salts are not enzymes.

T F 24. Proteases emulsify fats in preparation for digestion by sucrase.

T F 25. Glucose is a monosaccharide present in both animal and plant cells.

T F 26. Disaccharides can be separated into their individual monosaccharides by dehydration synthesis.

T F 27. Another name for blood sugar is galactose.

T F 28. Sugars are polysaccharides made up of units in chains.

T F 29. All lipids are soluble in water.

T F 30. The chief source of fat in the diet is animal tissue.

T F 31. Keratin and collagen are forms of waxes found in plant tissue.

T F 32. Collectively, the secretions of the salivary glands is called gastric juice.

T F 33. The hydrolysis of nutrients requires the presence of the appropriate enzymes and water.

T F 34. The wavelike series of contractions that move food along the digestive tract is called dehydration synthesis.

T F 35. The enzyme in the small intestine that digests fats and oils is trypsin.

T F 36. The end products of digestion are absorbed into the bloodstream in the large intestine.

T F 37. Lipids are converted into fatty acids and amino acids prior to being absorbed into the lacteals.

T F 38. Bile is stored in the gallbladder before it is delivered to the duodenum.

T F 39. The presence of fat in the duodenum triggers the release of cholecystokinin into the blood, causing contraction of the gallbladder and ejection of concentrated bile into the duodenum.

T F 40. Included in the pancreatic fluid emptied into the duodenum are such digestive enzymes as hydrochloric acid, amylase and pepsin.

T F 41. When stimulated by the entrance of acid substances from the stomach, the duodenum releases two hormones - secretin and pancreozymin - directly into the bloodstream.

T F 42. Vitamin B_1 and vitamin B_{12} are structurally parts of a coenzyme.

T F 43. For each enzyme, pH values above or below its particular optimum diminishes its effectiveness.

T F 44. The sight, hearing, thought and the smell of food are all capable of stimulating the salivary glands to secrete saliva.

T F 45. The secretion of pancreatic juice is under hormonal control. One of the hormones responsible for pancreatic secretion is called secretin.

T F 46. The enzyme pancreozymin is specifically responsible for the release of the digestive enzymes in pancreatic juice.

T F 47. Bile salts are digestive enzymes.

T F 48. Salivary amylase is a proteinase.

T F 49. The enzyme renin is present in the stomachs of all adult mammals.

T F 50. The secretions from the liver and pancreas are deposited directly into the bloodstream.

T F 51. Emulsification of fats is a chemical process.

T F 52. The production of bile ceases completely and abruptly following surgical removal of the gallbladder.

T F 53. The greater quantity of amino acids and glucose that arrive in the liver directly from the small intestine is retained in the liver for processing and storage.

54. Explain why enzymes are so important in biological systems.

55. List two inorganic co-factors.

(a) ____________________

(b) ____________________

56. Name the hormone that must be present in order for the gallbladder to release bile into the duodenum.

____

57. List three common categories of carbohydrates.

(a) ____________________

(b) ____________________

(c) ____________________

58. Provide other names used for the monosaccharide, glucose.

(a) ____________________

(b) ____________________

(c) ____________________

59. List three examples of disaccharides (double sugars).

(a) ____________________

(b) ____________________

(c) ____________________

60. Provide another name for glycogen.

____

61. Man is unable to utilize the polysaccharide cellulose as a food nutrient. Of what value, if any, is cellulose in the human diet?

____

____

62. What are oils?

____

____

63. List **six** forms in which proteins appear in the human body.

(a) ____________________

(b) ____________________

(c) ____________________

(d) ____________________

(e) ____________________

(f) ____________________

64. What is the epiglottis?

65. List the digestive enzymes at work in the stomach.

(a) ____________________

(b) ____________________

(c) ____________________

66. Differentiate between chyle and chyme.

67. Identify the function of the hepatic portal vein.

68. What is deamination?

69. List four salts normally required by the human body for proper functioning and maintenance.

(a) ______________________________

(b) ______________________________

(c) ______________________________

(d) ______________________________

70. List six processes and/or functions within the body which are aided by water.

(a) ______________________________

(b) ______________________________

(c) ______________________________

(d) ______________________________

(e) ______________________________

(f) ______________________________

71. List four disorders of the digestive tract of humans which you have studied in this lesson.

(a) ______________________________

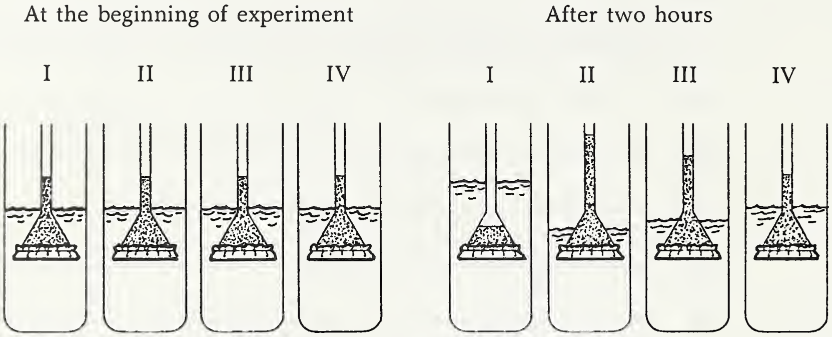
(b) ______________________________

(c) ______________________________

(d) ______________________________

Use the following information to answer question 72.

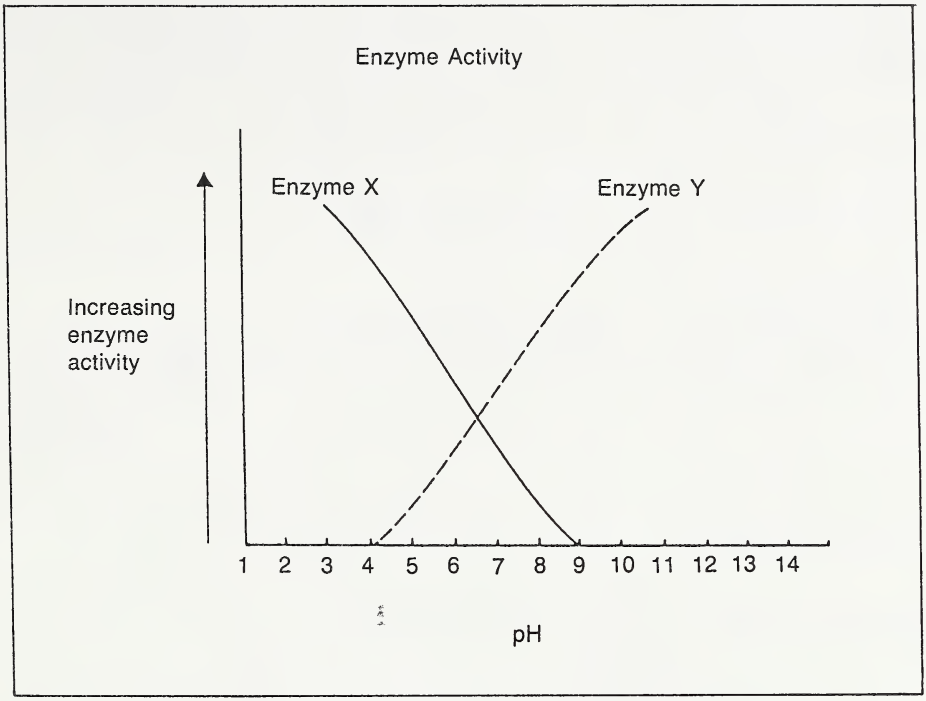
Four funnels are partially filled with various concentrations of a sugar solution and sealed with membranes that are impermeable to sugar and permeable to water. The funnels are then placed in beakers containing an initial 1% sugar solution and left for two hours.



_____ 72. Which funnel contained a 1% solution of sugar?

(a) I
(b) II
(c) III
(d) IV

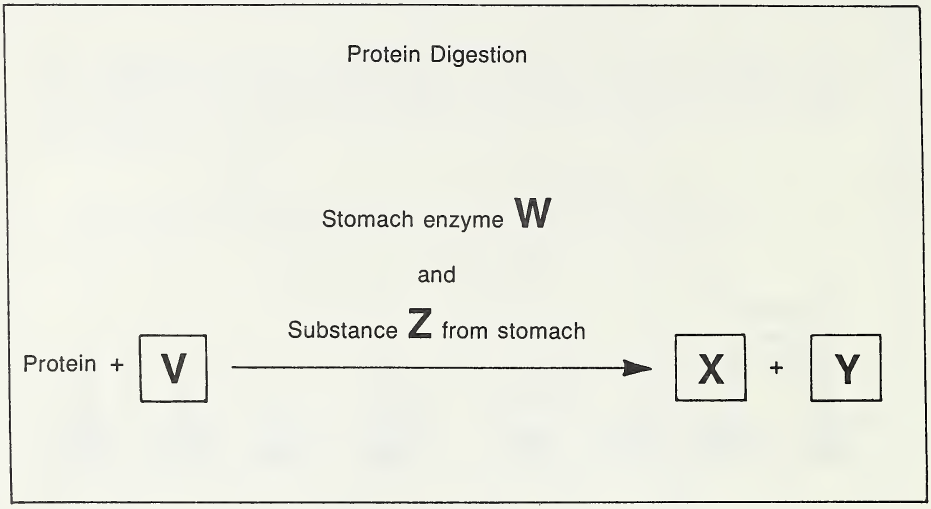
Use the following information to answer question 73.



____ 73. The digestion of protein is initiated by the enzyme labelled

(a) Y, which works best in the stomach
(b) X, which works best in the stomach
(c) X, which works best in the small intestine
(d) Y, which works best in the small intestine

Use the following information to answer question 74.



____ 74. Substance W could most likely be

(a) gastrin
(b) secretin
(c) pepsinogen
(d) hydrochloric acid

Please submit pages 46 to 56 for correction and grading.

END OF LESSON 5

LESSON RECORD FORM

3230 Biology 30
Revised 03/89

FOR STUDENT USE ONLY

Date Lesson Submitted ____________________

Time Spent on Lesson ____________________

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or incorrect)

File Number ____________________

Lesson Number ____________

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Mark: ________

Graded by: ________

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1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

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Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

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Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

CELLULAR RESPIRATION: OXIDATION OF GLUCOSE IN THE CELL

OBJECTIVES

At the conclusion of lesson 6 you should be able to carry out the following correctly:

1. **Distinguish** between anabolic and catabolic activities as integral parts of metabolism.
2. **Understand** the difference between cellular respiration and breathing.
3. **Recognize** that energy is released by breaking the bonds of food molecules that have been absorbed by cells.
4. **Recognize** that ATP (adenosine triphosphate) is a useful molecule for storing energy in cells.
5. **Understand** that ATP is a high energy molecule and that energy released from ATP is used to initiate various chemical reactions in the cell.
6. **Compare** oxidation and reduction reactions as they relate to the oxidation of glucose.
7. **Understand** that glucose can be oxidized anaerobically as well as aerobically during cellular respiration.
8. **Understand** the steps involved in anaerobic respiration (glycolysis).
9. **Define** "oxygen debt" and tell how it is repaid.
10. **Understand** the stages involved in aerobic respiration: glycolysis, citric acid cycle, and electron transport chain.
11. **Identify** the starting molecules, end products, and net ATP formed during anaerobic and aerobic respiration.
12. **Identify** where the various events of anaerobic and aerobic respiration take place in the cell.
13. **Visualize** the complete process of aerobic respiration from glucose to carbon dioxide and water, stating where it takes place and how much energy is gained.
14. **Write** a balanced equation for aerobic respiration.
15. **Understand** how ATP formed during cellular respiration is used during metabolic processes such as
    (a) active transport
    (b) synthesis of organic molecules
    (c) muscle contraction
16. **Show** how some energy, seemingly lost as heat, plays an important role in the maintenance and control of body temperature.
17. **Understand** that proteins and lipids can be oxidized by the same oxidative pathways as glucose.

CELLULAR RESPIRATION

READ

The information in this lesson is to be accompanied by the readings in your textbook (pp. 30 to 32). There is an error on p. 32 of the text. The oxidation of glucose produces 36 and not 38 molecules of ATP.

Introduction

The nutrients in food are essentially chemical substances which provide energy. There are six types of nutrients: carbohydrates, lipids, proteins, minerals, vitamins, and water. Carbohydrates, proteins and lipids are digested by enzymes in the gastrointestinal tract. The end products of digestion are monosaccharides, amino acids, and fatty acids and glycerides. After digestion has been completed, the end products are absorbed through the villi of the small intestine. The end products enter the bloodstream and are carried to the cells of the body. The cells make use of the energy contained in monosaccharides, amino acids, and fatty acids and glycerides.

Most of the end products of digestion are used to produce energy in order to support many life sustaining processes. For example, energy is needed for processes such as active transport, synthesis of complex organic compounds, muscular contraction, nerve impulse transmission, and DNA replication. The energy needed for these various life processes comes from the breaking of chemical bonds within the food molecules that have been absorbed by cells. Some of the end products of digestion are used to synthesize structural molecules in the cell or to synthesize regulatory molecules, such as hormones and enzymes.

Minerals, vitamins, and enzymes catalyze the energy producing reactions undergone by monosaccharides, amino acids, fatty acids, and glycerides in the cells of the body.

Water also has many important functions. One of the most important functions of water is that it participates in many hydrolysis reactions which occur in cells. During a hydrolysis reaction, water is added to a molecule causing it to break apart. When chemical bonds are broken within cells, energy is released.

Cells have a special molecule which stores and releases energy in small amounts. The molecule **ATP** (adenosine triphosphate) stores energy in its bonds until it is needed for cellular processes.

Metabolism involves a series of catabolic and anabolic chemical reactions. In other words, metabolism represents the sum of all the decomposition and synthesis reactions that occur in the cells. **Catabolic** reactions are energy yielding or decomposition reactions. **Anabolic** reactions are energy requiring reactions which involve the synthesis of new molecules within cells. Together these reactions may be thought of as performing an energy balancing act.

When we say that a person has a high metabolism, we mean that chemical reactions in the cells are proceeding at a faster rate than normal. The decomposition (catabolic) reactions are occurring so quickly that foods are broken down completely before the body has a chance to store them. Consequently, people with high metabolic rates can eat more food without the accompanying gain of weight.

On the other hand, people with low rates of metabolism tend to gain weight easily. This is due partly to the fact that digested food is stored rather than being rapidly metabolized. Because their synthesis (anabolic) reactions are also slowed down, their bodies build new molecules very slowly. Consequently, wounds take a long time to heal.

Cellular respiration can be described as a metabolic process whereby food energy is converted to a usable form of energy called ATP. Do not confuse cellular respiration with breathing, which is sometimes called respiration. Breathing is the exchange of two gases, oxygen and carbon dioxide, between the atmosphere and lungs. The mechanisms of breathing will be studied in lesson 8.

This lesson will focus on the metabolism of glucose in cells. Before we discuss the fate of glucose within cells, let us define various types of reactions that occur during cellular respiration.

Oxidation and Reduction

Cellular respiration is accompanied by oxidation-reduction reactions. **Oxidation** is the removal of hydrogen atoms from a molecule or, less commonly, the addition of oxygen to a molecule.

Since hydrogen atoms are composed of electrons and hydrogen ions, we can also say that oxidation is the removal of electrons and hydrogen ions. Typical oxidation reactions in the cells involve the removal of hydrogen ions and electrons from organic molecules such as glucose, amino acids, fatty acids, and glycerol. This lesson will only deal with the oxidation of glucose.

$$\boxed{H \rightarrow H^{+} + e^{-}}$$

hydrogen atom	hydrogen ion	electron

When hydrogen atoms or hydrogen ions and electrons are removed from organic molecules they have to be deposited somewhere. Thus, for every oxidation reaction there must be a corresponding reduction reaction. In chemistry **reduction** means either the addition of hydrogen atoms (i.e. hydrogen ions and electrons) to a molecule or, less commonly, the removal of oxygen from a molecule. Molecules that carry hydrogen atoms from one hydrogen acceptor to another are referred to as **coenzymes**. One of the strongest hydrogen acceptors in the cell is oxygen. When hydrogen and oxygen unite neutral water is formed. Water is a byproduct of respiration. If this did not occur, the hydrogen concentration would increase causing the cells and surrounding fluids to become dangerously acidic.

In this lesson it is important to realize that reduction is the opposite of oxidation and that oxidation-reduction (redox) reactions occur in pairs. Throughout this lesson we will define oxidation as the loss of hydrogen atoms (this includes hydrogen ions and electrons) and reduction as the gain of hydrogen atoms (this includes hydrogen ions and electrons).

A: represents any molecule that participates in oxidation-reduction reactions

$AH_2 \rightarrow A + H_2$ (oxidation)
(loss of hydrogen and its electron)

$A + H_2 \rightarrow AH_2$ (reduction)
(gain of hydrogen and its electron)

Self-Correcting Exercise 1

Complete the following statements by filling in the blanks.

1. The main source of energy from food is derived by the __________________ of bonds. The breaking of bonds within food molecules takes place in __________________. The energy released by the oxidation of food molecules is stored in molecules of __________________.
2. All normal cells are capable of __________________ glucose.
3. During cellular respiration the energy from food is converted to a more usable form of energy called __________________.
4. The word metabolism refers to the sum of all __________________ and __________________ reactions. When we say that a person has a high __________________, we mean that the chemical reactions in the cells are proceeding at a faster rate than normal.
5. Reactions where hydrogen atoms are lost are known as __________________ reactions. Reactions where hydrogen ions and __________________ are gained are known as __________________ reactions. These reactions occur in pairs. Hydrogen acceptors in cells are referred to as __________________.

Check your answers with those on page 35. Correct any errors that you may have.

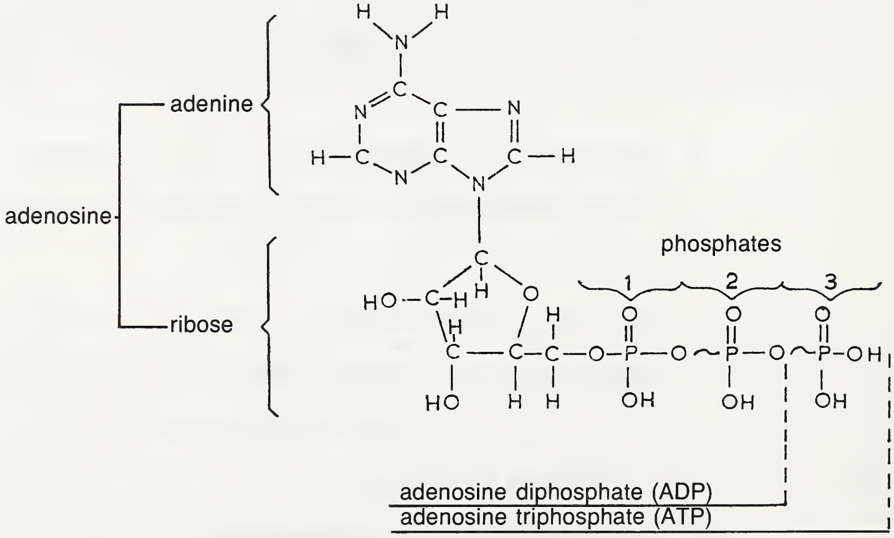
Glucose - The Body's Most Essential Nutrient

Glucose is the body's preferred nutrient for oxidation, however, amino acid, fatty acids, and glycerol are also oxidized. Oxidation also involves the production of ATP from ADP (adenosine diphosphate). Energy is produced as substances are oxidized. The energy is removed step by step and ultimately trapped in ATP for storage. When the cells need energy, ATP is broken down and the energy is released.

It is imperative to the human body that energy be stored in molecules of ATP (adenosine triphosphate) and used only when needed. If an individual ate glucose and all the energy was freed at one time, the body temperature would rise drastically. A temperature rise of this sort would cause proteins (i.e. enzymes) to coagulate. In effect, this sudden burst of energy from food would mean self-incineration after every meal! That is why energy is stored and redistributed among the bonds of reacting molecules like ATP.

Adenosine Triphosphate (ATP)

The following diagram does not have to be memorized, it merely shows the different components of the ATP molecule:



The only difference between a molecule of ATP (adenosine triphosphate) and a molecule of ADP (adenosine diphosphate) is that the 3rd terminal phosphate group is absent in ADP and present in ATP.

Simplified diagram of ATP (adenosine triphosphate)

1. ADENOSINE — P ~ P ~ P

~ represents a high energy bond
— represents a low energy bond

Simplified diagram of ADP (adenosine diphosphate)

2. ADENOSINE — P ~ P

The bond between the second and third phosphates of ATP releases a great deal of energy when it is broken. These bonds are **high energy bonds** (~). When a terminal phosphate group is removed from ATP it becomes ADP and energy is released. When phosphate and energy are added to ADP it becomes ATP and is thus energized. The ATP ↔ ADP reaction shuttles energy back and forth between energy requiring and energy yielding reactions of the cell.

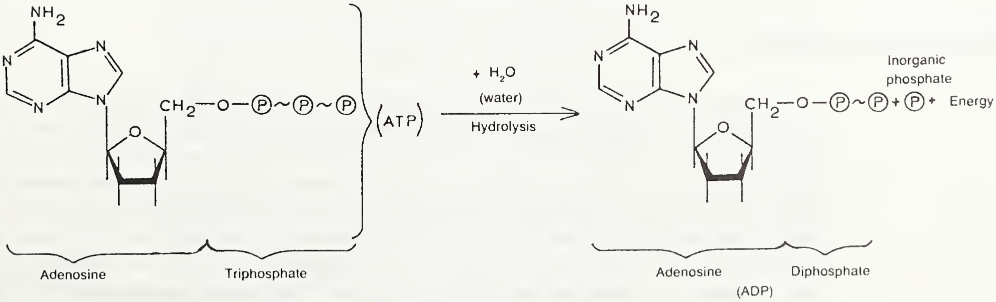
When a high energy bond (~) is broken, more energy is released than when a low energy bond (—) is broken.

ADENOSINE — P ~ P ~ P ⇌ ADENOSINE — P ~ P + P + ENERGY

The double arrows of the reaction above shows that the reaction can go either way. Remaking ATP is more difficult than breaking the bonds. To form ATP, energy and phosphate (P) must be added back to ADP.

Hydrolysis (addition of water) is needed to break apart the ATP molecule during energy yielding reactions in the cell.

Simplified diagram of hydrolysis



Self-Correcting Exercise 2

Fill in the blanks and answer the questions.

1. ATP stands for ______________________________.
2. List the three components of ATP:

   (a) ______________________________

   (b) ______________________________

   (c) ______________________________
3. ATP is a complex molecule. Adenosine is one of its components. Adenosine is composed of the molecules ______________ and ______________. Attached to the adenosine molecule are three ______________ groups.
4. What do we mean by the term "high energy bond"?

   ____

   ____
5. ATP may be synthesized in the cell by adding ______________ and ______________ to ADP.
6. ATP can decompose into ADP and ______________ by the process of ______________. This is an energy ______________ reaction.

Check your answers with those on page 35. Correct any errors that you may have.

Carbohydrate Metabolism

During the process of digestion, polysaccharides and disaccharides are hydrolyzed. Hydrolysis is essentially a decomposition reaction which involves the splitting of molecular bonds with the addition of water. After hydrolysis the polysaccharides (i.e. starches) and disaccharides (i.e. maltose, lactose, sucrose) become simple sugars or monosaccharides (i.e. glucose, fructose, and galactose) which are absorbed into the capillaries of the villi of the small intestine. The monosaccharides are transported to the liver via the hepatic portal vein, where fructose and galactose are converted to **glucose**. The liver is the only organ that has the necessary enzymes to make this conversion. **Thus when we discuss the metabolism of carbohydrates, we are really talking about glucose metabolism.**

The Fate of Glucose

Since glucose is the body's major source of energy, the fate of glucose after it has been absorbed into the cells, depends on the energy needs of the body cells. If the cells require immediate energy, the glucose is oxidized by the cells. When glucose is not needed immediately, the body has several ways to process it:

1. Glucose can be converted to glycogen by the liver. Glycogen can be stored in the liver and skeletal muscle cells as a future energy source for body cells.

2. If the glycogen storage areas are all filled, the liver can convert the excess glucose to fat that can be stored in adipose tissue. Later, when the cells require energy, the stored fat and glycogen are converted back to glucose by the liver. Then the glucose travels through the bloodstream to the cells where it is finally oxidized.

3. The excess glucose can be excreted in the urine. Glycosuria (glucose in the urine) occurs only when a meal containing large amounts of carbohydrates and no fats has been consumed. Without the presence of fats, the stomach quickly empties its contents into the small intestine and all the carbohydrates are finally digested at the same time. Consequently, a flood of monosaccharides are transported into the bloodstream. The liver is unable to handle the flood of monosaccharides; therefore, blood glucose rises. This condition of high blood glucose or hyperglycemia may eventually result in glucose in the urine (glycosuria).

Self-Correcting Exercise 3

Fill in the blanks and answer the questions.

1. Polysaccharides and disaccharides are broken down into ____________________

   by the process of ____________________.

2. Glucose, fructose, and galactose are monosaccharides which are absorbed into the villi

   of the small intestine and transported by the bloodstream to the ____________________.

   Here the monosaccharides are converted to ____________________. Thus the story of carbohydrate metabolism is really the story of glucose metabolism.

3. ____________________ is the body's major source of energy.

4. When the cells require energy, glucose is ____________________.

5. When the cells do not require glucose immediately, the body has three basic ways of processing it:

(a) ______________________________

____

(b) ______________________________

____

(c) ______________________________

____

6. What do you think would happen to cells if all of the energy in glucose were utilized at once during the process of carbohydrate metabolism? Explain.

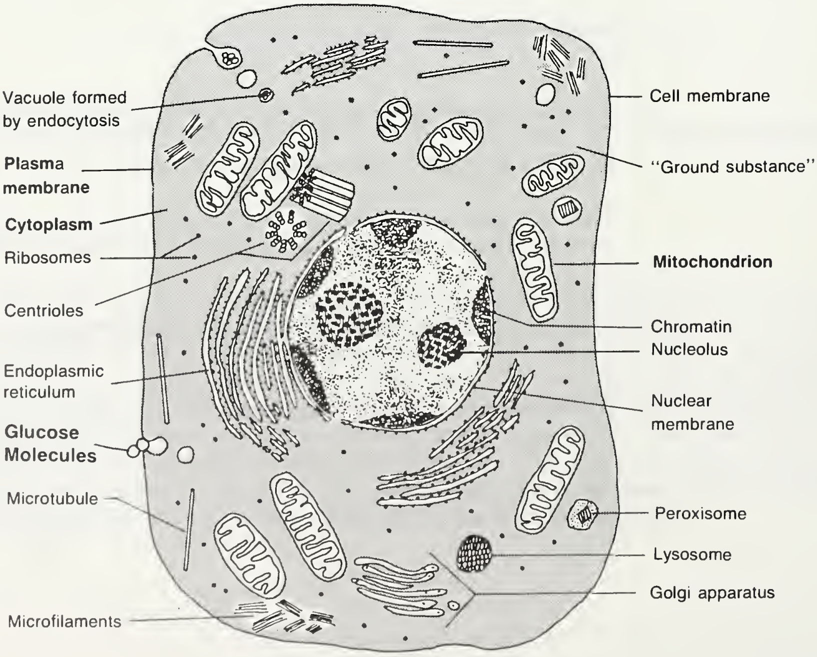
____

____

Check your answers with those on page 36. Correct any errors that you may have.

The Movement of Glucose into Cells

Before glucose can be used by each individual body cell, it must first penetrate the plasma membrane and then enter the cytoplasm.



As you know from the readings in lesson 1, cells are complex structures. The organelles inside each individual cell perform various specialized activities to ensure its survival. In this lesson we will only focus on the **cytoplasm** and **mitochondria** since most of the reactions involved in cellular respiration take place here.

Phosphorylation of Glucose

There is one basic process which facilitates the entry of glucose into the cytoplasm of cells: the pancreas increases the secretion of insulin into the bloodstream. Insulin increases the permeability of cells to glucose.

Upon entry into cells, glucose immediately combines with a phosphate group, produced by the breakdown of ATP. The addition of a phosphate group to glucose is called **phosphorylation**. Phosphorylation is an enzyme catalyzed reaction which results in the formation of glucose phosphate. The addition of a phosphate to glucose converts it from a substance that can leave the cell to one that cannot pass across the plasma membrane. The glucose molecule is trapped inside the cell where cytoplasmic enzymes can alter the structure. The phosphorylation of glucose activates it and renders it more chemically reactive.

Glucose Catabolism

Glucose catabolism involves the oxidation of glucose which is also known as **cellular respiration**. Cellular respiration occurs in the cells of the body to provide energy for cellular activities. The complete oxidation of glucose to carbon dioxide and water produces large amounts of energy. Cellular respiration occurs in three successive stages: **glycolysis,** the **citric acid cycle,** and the **electron transport chain.**

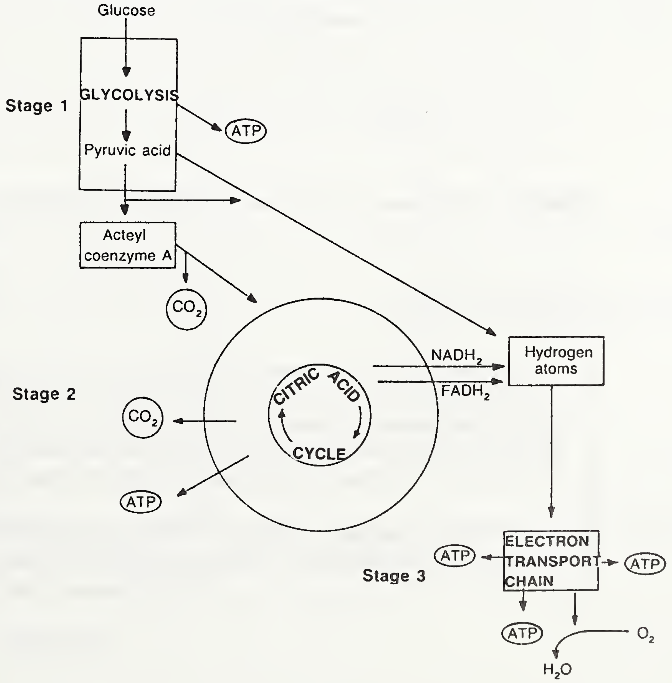


Figure 1: Summary of the complete oxidation of glucose.

Self-Correcting Exercise 4

Fill in the blanks and answer the questions.

1. The oxidation of glucose is also known as ____________ ____________.
2. When glucose enters the cytoplasm of cells it is immediately ____________ with the addition of a phosphate group.
3. The phosphorylation of glucose enables the molecule to

   (a) ____

   ____

   (b) ____

   ____

4. Cellular respiration occurs in three successive stages:

   (a) ____

   (b) ____

   (c) ____

5. What do you think would happen to your body if phosphorus was eliminated from your diet? (Good sources of phosphorus are dairy products, meat, fish, poultry, nuts.)

   ____

   ____

   ____

Check your answers with those on page 36. Correct any errors that you may have.

Attention Students

Please note that you are not required to memorize the detailed steps involved in cellular respiration (i.e. glycolysis, critic acid cycle, electron transport chain). These detailed steps were included in this lesson to enrich your understanding of cellular respiration. Furthermore, you do not have to memorize chemical formulas for the various products and intermediate products of cellular respiration.

If you successfully complete the self-correcting exercises as well as the exercises to be sent in for correction, you have fulfilled the main objectives of this lesson.

Cellular Respiration Begins

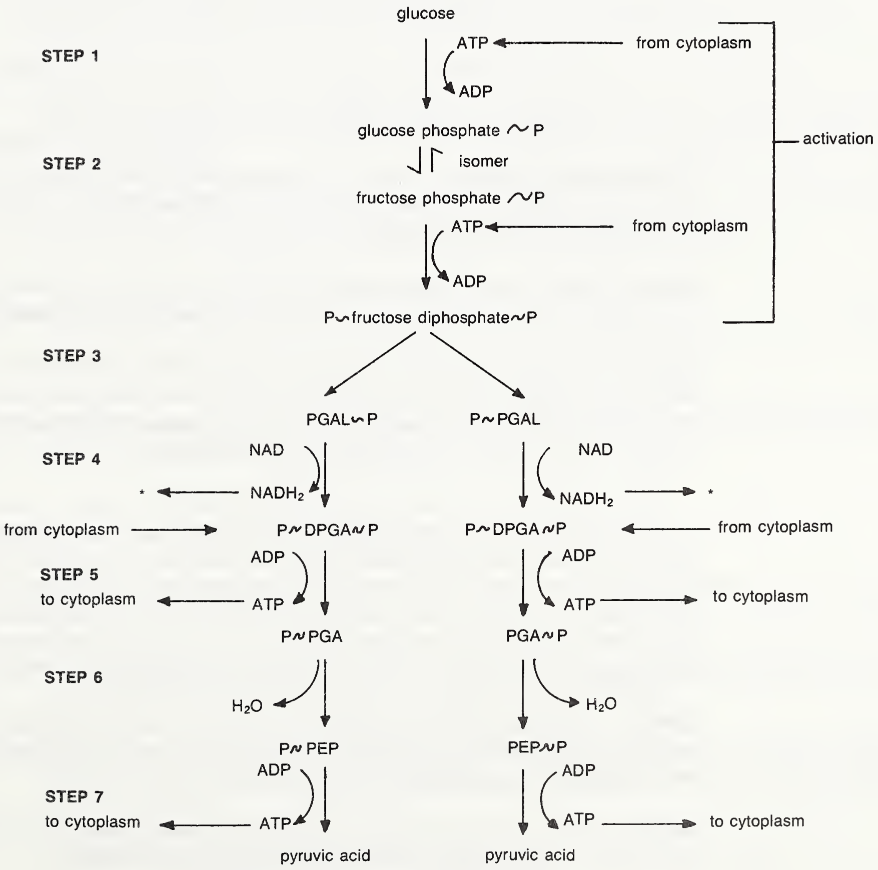
Glycolysis (Stage 1)

Glycolysis is a series of chemical reactions that occur in the cytoplasm of cells. It is a process whereby a six-carbon molecule of glucose ($C_6H_{12}O_6$) is converted into two three-carbon molecules of pyruvic acid ($C_3H_4O_3$). Glycolysis does not require the presence of oxygen. The overall simplified equation for glycolysis is:

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \rightarrow \underset{\text{pyruvic acid}}{2C_3H_4O_3} + 2ATP$$

The breakdown of glucose occurs in steps. Each of these reactions is catalyzed by a series of specific enzymes. We will not identify the names of enzymes in this lesson. You can follow the various steps outlined in glycolysis by looking at figure 2.

Glycolysis



*transferred to electron transport chain

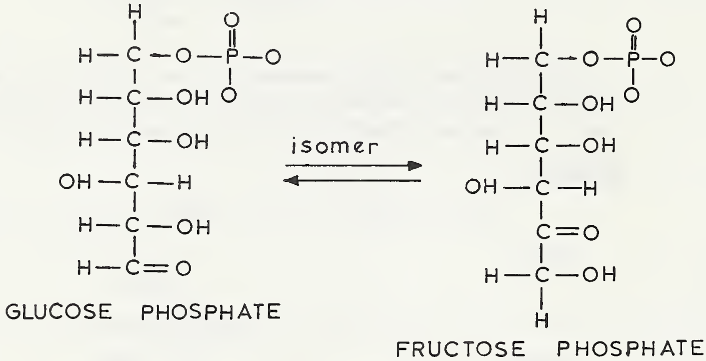
Figure 2: Glycolysis

Step 1: The cell must supply the activation energy needed to initiate the breakdown of glucose. The energy is supplied by attaching a phosphate group from ATP to glucose. The **glucose** becomes **glucose phosphate**. This step as you recall is called the **phosphorylation of glucose**.

Step 2: Glucose phosphate is rearranged by the cell into a new molecule called **fructose phosphate**. Fructose phosphate is an **isomer** of glucose phosphate. An isomer has the same molecular formula but a different structural formula.

Diagram:

Structural Formulas



More energy is required to start the reaction so another phosphate group from ATP is attached to fructose phosphate, turning it into **fructose diphosphate**. At this point 2ATP have been used in the process of glycolysis.

Step 3: After being activated sufficiently, the six-carbon molecule fructose diphosphate splits into two three-carbon molecules called **phosphoglyceraldehyde (PGAL).**

Step 4: Energy from ATP was needed to activate all these molecules, now energy can be derived from them. A hydrogen ion is removed and a phosphate group from the cytoplasm is added to each PGAL molecule to form two molecules of **diphosphoglyceric acid (DPGA).** In other words, PGAL is **oxidized** and **phosphorylated** to form DPGA.

The hydrogen ions that were removed from the PGAL molecules are accepted by coenzyme NAD (nicotinamide adenine dinucleotide) and transferred to the electron transport chain for further energy release. NAD is an essential coenzyme synthesized from vitamin B_3 (niacin or nicotinic acid); therefore, it is recommended that foods containing this vitamin be included in the diet. Meat, poultry, fish, and whole wheat grains all contain vitamin B_3. If your body is not supplied with vitamin B_3, it would not be able to synthesize coenzyme NAD, consequently the process of deriving energy from food would be most inefficient.

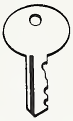
Step 5: Phosphate groups transfer their energy to ADP, resulting in the formation of two molecules of ATP. This reaction also results in the formation of **phosphoglyceric acid (PGA)** molecules from each DPGA.

Step 6: The cell now removes a molecule of water from each PGA and rearranges the molecules of PGA to form **phosphoenol pyruvic acid (PEP).**

Step 7: The phosphate bond in PEP has a higher energy than it did in PGA. The cell now removes the phosphate group from each PEP molecule and uses it to convert ADP to ATP. This results in the formation of two molecules of **pyruvic acid** and completes the process of glycolysis.

Glycolysis results in a net yield of two ATP: As you recall four ATP were produced and two ATP were used to start the reaction. This results in the net gain of two ATP. The cell uses the energy in ATP molecules for various cellular processes.

Self-Correcting Exercise 5



Fill in the blanks and answer the question.

1. Glycolysis is a series of chemical reactions which are catalyzed by specific enzymes.

   Glycolysis occurs in the ______________ of cells.

2. During glycolysis, glucose is converted to two molecules of ______________ ______________.

3. The total number of ATP formed by glycolysis is ______________ ATP. Two of these were used to activate glucose. This leaves a **net energy gain** of ______________ ATP.

4. What factors do you think would inhibit the process of glycolysis?

   ____

   ____

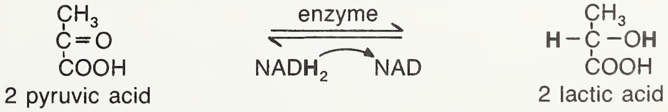
Check your answers with those on page 37. Correct any errors that you may have.

The Fate of Pyruvic Acid

The fate of pyruvic acid depends on the availability of oxygen. There are two possible outcomes:

1. During **anaerobic conditions** when oxygen is not available, pyruvic acid is reduced by the addition of two hydrogen atoms to form **lactic acid**.

   The formation of **lactic acid** occurs in the muscle cells during strenuous exercise. This is called **anaerobic respiration**. Anaerobic respiration occurs in the cytoplasm of muscle cells.

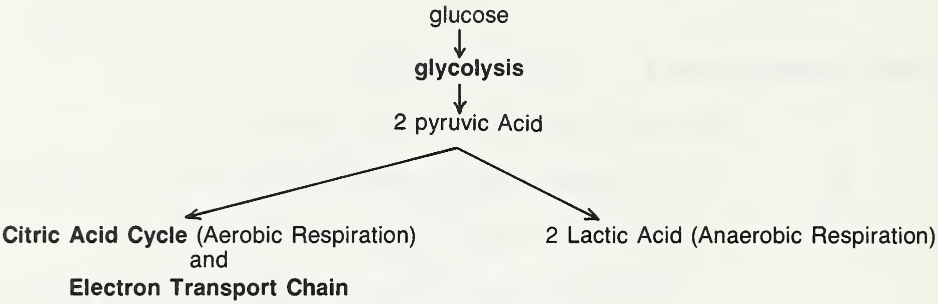


$$\underset{\text{2 pyruvic acid}}{\begin{matrix} CH_3 \\ | \\ C=O \\ | \\ COOH \end{matrix}} \quad \underset{NADH_2 \;\to\; NAD}{\xrightleftharpoons{\text{enzyme}}} \quad \underset{\text{2 lactic acid}}{\begin{matrix} CH_3 \\ | \\ H-C-OH \\ | \\ COOH \end{matrix}}$$

2. Under **aerobic conditions**, when enough oxygen is available, pyruvic acid is oxidized to form carbon dioxide and water in two sets of reactions: the **citric acid cycle** and the **electron transport chain. Aerobic respiration** occurs in the **mitochondria** of cells.

   The implications of aerobic respiration will be discussed in greater detail later in this lesson.

Summary:


glucose
glycolysis
2 pyruvic Acid
Citric Acid Cycle (Aerobic Respiration)
and
Electron Transport Chain
2 Lactic Acid (Anaerobic Respiration)

Let us discuss the reactions of anaerobic respiration. In other words, let us discuss what happens to pyruvic acid during anaerobic conditions.

Anaerobic Respiration

In human beings, anaerobic respiration takes place most commonly in muscle tissue during strenuous exercise. In other words, muscle cells use glucose for energy without the presence of oxygen. Some parts of our body such as the brain, cannot undergo anaerobic respiration because brain cells need a constant supply of oxygen. Without oxygen brain cells die. Our muscles, on the other hand, do great amounts of work in a short period of time and although our rate of breathing and heart rate increase during exertion, oxygen cannot be supplied in sufficient quantities to permit aerobic respiration. Thus muscles have a unique ability of operating under anaerobic conditions.

During anaerobic respiration glucose is converted to pyruvic acid which in turn is converted to lactic acid. Lactic acid accumulates in the muscle.

$$\underset{\text{glucose}}{C_6H_{12}O_6} \overset{\text{enzyme}}{\rightleftharpoons} \underset{\text{pyruvic acid}}{2C_3H_4O_3} \underset{NADH_2 \curvearrowright NAD}{\overset{\text{enzyme}}{\rightleftharpoons}} \underset{\text{lactic acid}}{2C_3H_6O_3}$$

While running the 100-metre dash, glucose is broken down to lactic acid faster than it can be reconverted to glucose by the liver. Lactic acid accumulates in the muscle causing cramps and muscle fatigue. Taken to an extreme, the muscle may become exhausted and be unable to contract. This is because the accumulation of lactic acid lowers the pH of the muscle fluids (i.e. muscle fluids become acidic). If the pH shift is too great, the muscle fibre loses its ability to contract, thus becoming fatigued.

There are other factors that contribute to muscle fatigue. Fatigue results partly from the toxic effects of lactic acid and carbon dioxide accumulated during strenuous exercise and partly from the lack of oxygen availability during anaerobic conditions.

After strenuous exercise, the muscle is said to have incurred an "**oxygen debt.**" This debt is repaid by breathing rapidly and deeply after this extreme muscle activity. The greater the level of exertion, the longer the period of heavy breathing will be. When enough oxygen is available, the muscle cramps disappear.

As oxygen enters the cells, the oxygen debt is paid off. Now lactic acid can diffuse out of the muscle cells (by way of the intracellular channels provided by the endoplasmic reticulum) and be carried by the surrounding body fluids and plasma to the liver. Here lactic acid is resynthesized into glycogen using energy from cellular respiration. Later, the glucose required by the muscles, restored as glycogen from the liver, is broken down into glucose and delivered to the muscles by the bloodstream. Thus during a long race, a runner may get a "second wind." Because of his increase in breathing and heart rate, he takes in enough oxygen to oxidize some of the lactic acid back into glucose thus paying off the oxygen debt.

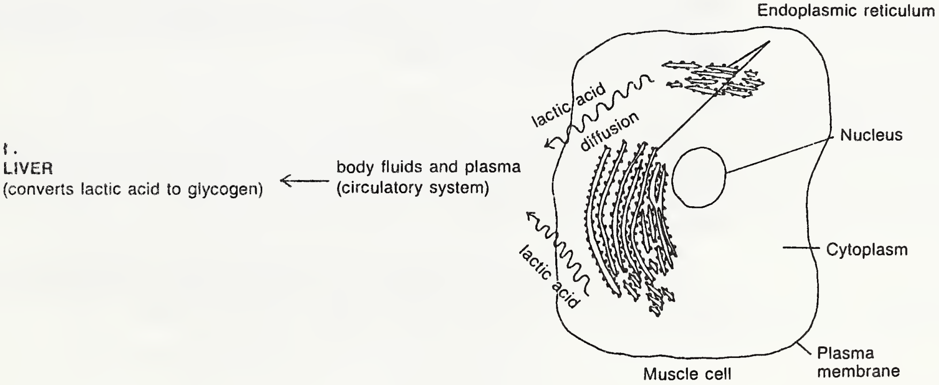


Figure 3: This is a diagram of lactic acid being transported out of the muscle cell by the endoplasmic reticulum. Lactic acid enters the circulatory system and is transported to the liver where it is converted to glycogen.

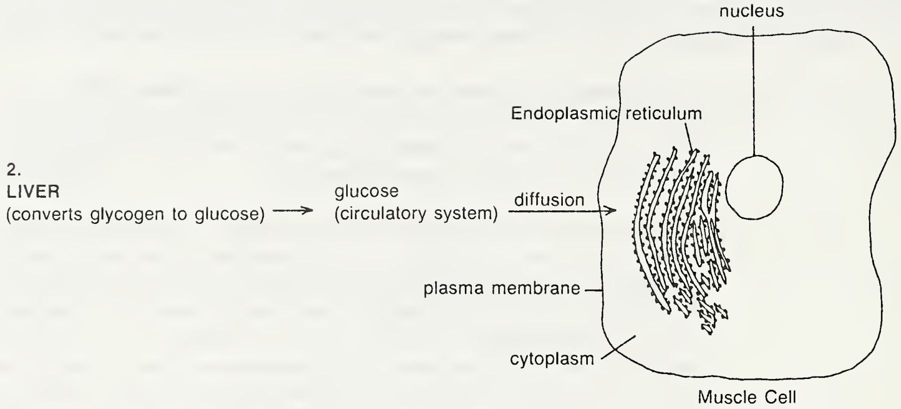


Figure 4: This diagram demonstrates another function of the liver. Glycogen in the liver is converted to glucose which is carried by the blood stream and transported to the muscle cells by the process of diffusion.

Before we begin our discussion about aerobic respiration, it is important to note that only a small fraction of the energy of glucose is released in the anaerobic conversion to lactic acid. Much more energy can be extracted aerobically via the citric acid cycle and the electron transport chain.

Now let us discuss the reactions involved in aerobic respiration. In other words, let us look at the fate of pyruvic acid during aerobic conditions.

Self-Correcting Exercise 6

Fill in the blanks and answer the question.

1. During glycolysis, ______________ is converted to two molecules of ______________ ______________. The fate of pyruvic acid depends on the availability of ______________.

2. When oxygen is not available (anaerobic conditions), pyruvic acid is reduced to ______________ ______________. Anaerobic respiration occurs in the ______________ of muscle cells.

3. When oxygen is available (aerobic conditions), pyruvic acid is oxidized to ______________ ______________ and ______________. Aerobic respiration occurs in the ________________________ of body cells.

4. The three stages of aerobic respiration are:

   (a) ____

   (b) ____

   (c) ____

5. Anaerobic respiration occurs in two basic stages:

   (a) ____

   (b) conversion of pyruvic acid to lactic acid

6. The accumulation of lactic acid in muscle cells, during anaerobic conditions, is a result of ______________ debt. A large amount of lactic acid in muscle cells causes muscle ______________.

7. After strenuous exercise, the muscle is said to have incurred an oxygen debt. This debt is repaid by breathing ______________ and ______________. As oxygen enters the muscle cells, lactic acid leaves. Lactic acid is transported by the circulatory system to the ______________ where it is converted back to ______________.

8. What do you think would happen to your body if it did not have a homeostatic mechanism for reducing the amount of lactic acid build-up in the muscle cells?

____

____

____

Check your answers with those on page 37. Correct any errors that you may have.

Aerobic Respiration

During the transitional step between glycolysis and the citric acid cycle, pyruvic acid is prepared for entrance into the citric acid cycle. Pyruvic acid is converted to a two-carbon compound (acetylgroup) by the loss of carbon dioxide (CO_2). The loss of a molecule of carbon dioxide (CO_2) by a substance is referred to as **decarboxylation**. The two-carbon compound, called an **acetyl group**, attaches itself to **coenzyme A**, and the whole complex is called **acetyl coenzyme A**. Thus pyruvic acid can enter the citric acid cycle only after it has been converted to **acetyl coenzyme A** in the mitochondria. The citric acid cycle occurs in the mitochondria; the formation of acetyl coenzyme A from pyruvic acid is the first point of entry into the citric acid cycle.

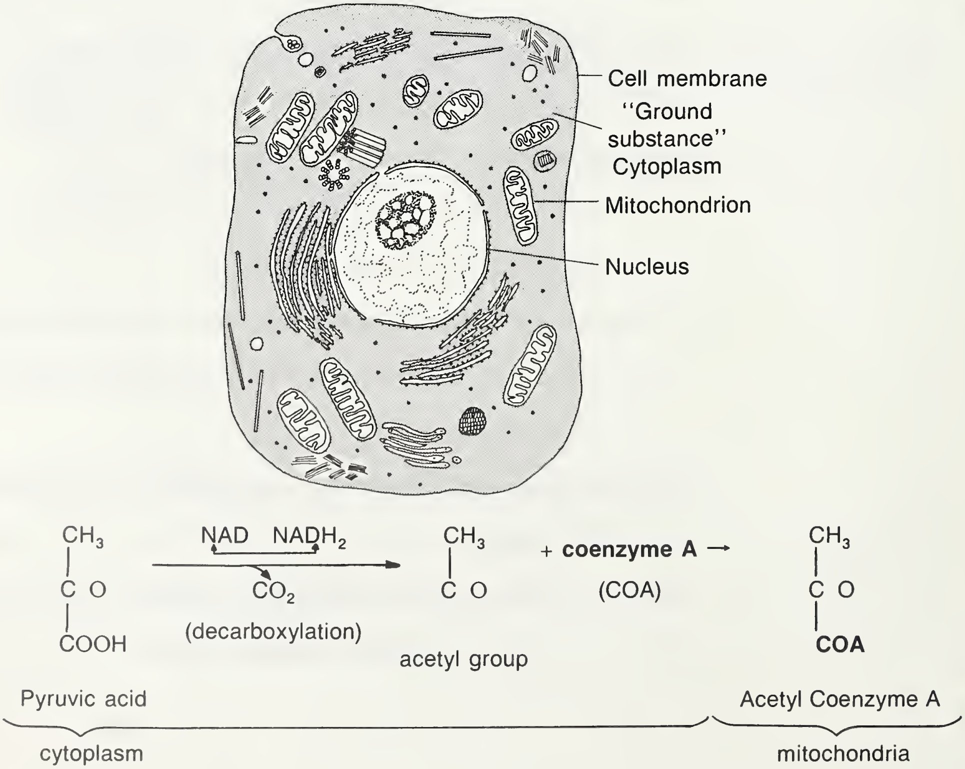


Figure 5: Formation of acetyl coenzyme A from pyruvic acid for entrance into the citric acid cycle.

Before we discuss aerobic respiration in terms of the citric acid cycle and the electron transport chain, let us briefly identify the major role of enzymes and coenzymes involved in these processes. As you know all **enzymes** are protein in nature and many enzymes are attached to nonprotein compounds. If a nonprotein group detaches from the enzyme and acts as a carrier molecule it is called a **coenzyme**. Enzymes and coenzymes work together. Enzymes catalyze (speed up) reactions and coenzymes attach to the end products of reactions and help to carry molecules to the next reaction. Each step in the oxidation of glucose requires a different enzyme and often a coenzyme as well. We will not review the names of all the enzymes involved in anaerobic and aerobic respiration. However, coenzymes such as coenzyme A, FAD, and NAD will be mentioned throughout the lesson as they play a major role in anaerobic and aerobic respiration.

Self-Correcting Exercise 7

Fill in the blanks.

1. Aerobic respiration has three basic stages:

   (a) ________________________________

   (b) ________________________________

   (c) ________________________________

2. Pyruvic acid was formed at the end of glycolysis. When enough oxygen is available (aerobic conditions), pyruvic acid is prepared to enter the ____________ ____________ ____________.

3. Pyruvic acid is converted to ____________ ____________ in the mitochondria of cells. Pyruvic acid is converted to ____________ ____________ by the loss of ____________ ____________ (decarboxylation) and the addition of coenzyme A. Once pyruvic acid is converted to ____________ ____________, it can enter the citric acid cycle.

4. A series of molecules called ____________ are used to catalyze reactions in both the anaerobic and aerobic phase of respiration. These molecules are ____________ in nature.

5. Coenzymes work together with ________________. Instead of catalyzing reactions as ________________ do, coenzymes act as carrier molecules. Three examples of coenzymes are (a) ____________________

(b) ____________________

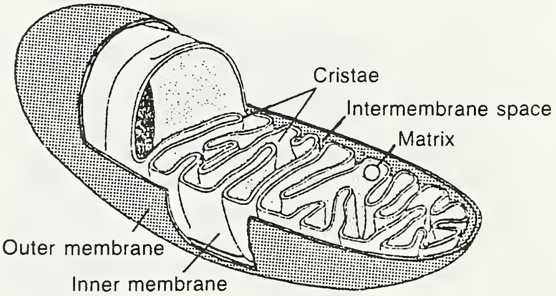
(c) ____________________

Check your answers with those on page 38. Correct any errors that you may have.

Citric Acid Cycle (Stage 2)

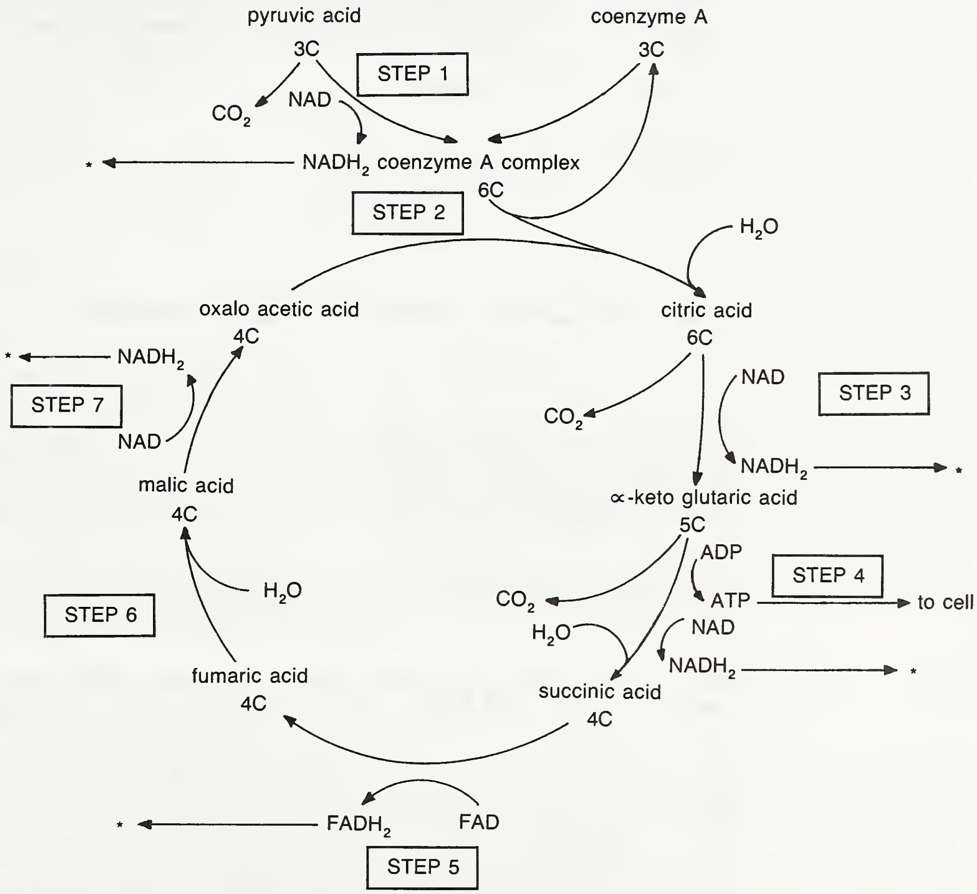
The **citric acid cycle** is also called the Krebs cycle, named after its discoverer Hans Krebs. It is a series of reactions that take place in the **matrix** of the **mitochondria** of cells. Let us take a close up look at a single mitochondrion to see exactly where the citric acid cycle has its base of operation.

A Single Mitochondrion



The following is a diagram of the citric acid cycle. Follow the steps outlined in Figure 6 as we continue discussing the role of the citric acid cycle in the aerobic phase of respiration. The citric acid cycle occurs in the matrix of the mitochondria.

Figure 6:



* transferred to the electron transport chain located in the cristae of the mitochondria.

Steps in the Citric Acid Cycle

Step 1: As you know the point of entry to this oxidative pathway (citric acid cycle) is acetyl coenzyme A (acetyl CoA) which is formed inside the mitochondria by the oxidative decarboxylation of pyruvic acid and the addition of coenzyme A.

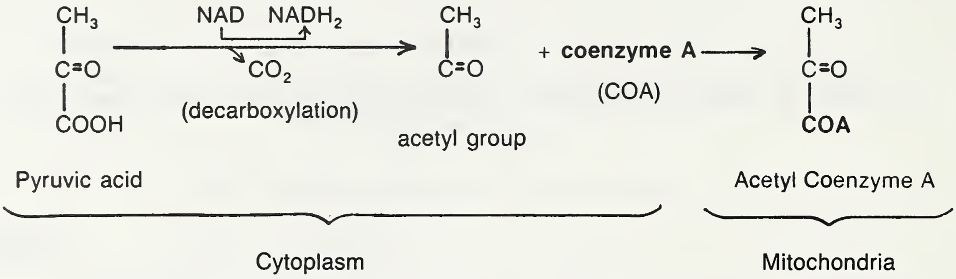


Figure 7: Conversion of pyruvic acid to acetyl coenzyme A.

In the conversion of pyruvic acid to acetyl coenzyme A, pyruvic acid loses a molecule of carbon dioxide (CO_2). This is called decarboxylation. Pyruvic acid also loses hydrogen atoms, that is, it is oxidized. The hydrogen atoms are picked up by coenzyme NAD (nitocinamide adenine dinucleotide). Since NAD picks up the hydrogen atoms, it is reduced and represented as $NADH_2$. The hydrogen atoms are carried to the electron transport chain by NAD. The significance of the electron transport chain will be discussed later in this lesson.

Coenzyme A attaches to the acetyl group forming the complex acetyl coenzyme A (acetyl CoA). In essence, coenzyme A carries the acetyl group to a mitochondrion, where it detaches itself and goes back into the cytoplasm to pick up another acetyl group. (See Figure 7).

Step 2: The acetyl group (2-carbon compound) combines with oxaloacetic acid (4-carbon compound) to form **citric acid** (6-carbon compound), which is why the cycle for aerobic respiration is given that name. The addition of water is also needed in the formation of **citric acid**. From this point the citric acid cycle consists mainly of a series of decarboxylations and oxidation-reduction reactions, each catalyzed by different enzymes. There are many other intermediate products that form within the citric acid cycle as a result of the breakdown of citric acid. However, only the step by step formation of the major products of the citric acid cycle will be discussed in this lesson. **Keep in mind also that you are not required to memorize the various steps in the citric acid cycle. These steps are included in the lesson to further your understanding of the topic "Cellular Respiration."**

Step 3: Hydrogen atoms and a molecule of carbon dioxide are removed from citric acid to form **ketoglutaric acid** (5-carbon compound). In other words, citric acid is oxidized to form ketoglutaric acid. The hydrogen atoms are transferred to the electron transport chain by NAD. As NAD picks up the hydrogen atoms it becomes reduced and is represented as $NADH_2$. Notice that for every oxidation reaction there is a corresponding reduction reaction. Coenzyme NAD transfers the hydrogens from the mitochondrial matrix to the inner mitochondrial membranes (cristae) where the electron transport chain is located. What happens to the hydrogens in the electron transport chain will be discussed later on in this lesson.

Step 4: Another pair of hydrogen atoms and a molecule of carbon dioxide is removed from ketoglutaric acid while a water molecule is added. This results in the formation of **succinic acid** (4-carbon compound). During these reactions ADP is converted to ATP and the two hydrogen atoms are transferred to the electron transport chain by coenzyme NAD (nicotinamide adenine dinucleotide).

To summarize, succinic acid is oxidized to fumaric acid as it loses the hydrogen atoms. Note that hydrogen atoms are composed of hydrogen ions and electrons and that these are lost as well. For every oxidation reaction there is always a reduction reaction; therefore, NAD is reduced to $NADH_2$ as a result of NAD picking up the hydrogen atoms lost by succinic acid.

Step 5: Another pair of hydrogen atoms are removed from the succinic acid and transferred by coenzyme FAD (flavin adenine dinucleotide) to the electron transport chain which is located in the mitochondrial cristae (inner membranes). This process converts succinic acid to **fumaric acid** (4-carbon compound).

Coenzyme FAD is derived from vitamin B_2 (riboflavin). As FAD picks up the pair of hydrogen atoms it is reduced and represented as $FADH_2$.

Step 6: Fumaric acid is converted to **malic acid** (4-carbon compound) by the addition of a molecule of water.

Step 7: A pair of hydrogen atoms are removed from malic acid and transferred to the electron transport chain by coenzyme NAD which becomes reduced to $NADH_2$ in the process. In other words, malic acid is oxidized to **oxaloacetic acid** and NAD is reduced to $NADH_2$. The regeneration of oxaloacetic acid marks one complete turn of the citric acid cycle. The cycle starts over again as oxaloacetic acid picks up another acetyl group to form citric acid. As long as oxygen is available, the citric acid cycle continues in its cyclic pattern generating more ATP for cellular activity.

Citric Acid Cycle - The Generation of ATP

ATP is generated at step 4 of the citric acid cycle where ketoglutaric acid is oxidized to succinic acid. (See figure 6.) However, there are two pyruvic acid molecules being converted to acetyl coenzyme A. These two molecules are processed through the citric acid cycle, thus the total amount of ATP generated is **2ATP**. This does not represent all of the energy that can be derived from glucose (original source). The next stage is the electron transport chain and it is this stage that represents the complete oxidation of glucose. The electron transport chain will be discussed later on in this lesson.

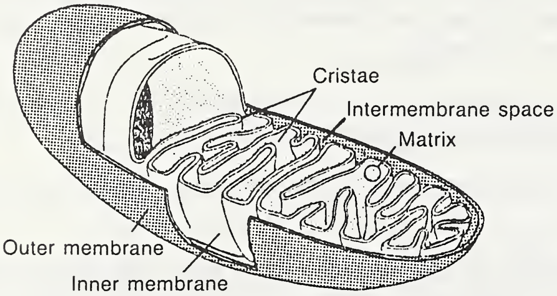
More about the Citric Acid Cycle

Each time two molecules of pyruvic acid enter the citric acid cycle, six molecules of $NADH_2$ and two molecules of $FADH_2$ are produced by the various oxidation-reduction reactions (see figure 6). These reduced coenzymes are very important because they now contain the stored energy originally in glucose and then in pyruvic acid. Carbon dioxide is also released as a result of the operation of the citric acid cycle. Carbon dioxide is a by-product of cellular respiration. It is also a waste product of cellular respiration. About 5-10 percent of the carbon dioxide is transported by the plasma in the form of bicarbonate ion (HCO_3^-). The rest of the carbon dioxide is picked up by the hemoglobin in the red blood cells and is eventually delivered to the lungs where it is eliminated by exhalation.

The next stage is the electron transport chain. It represents the complete oxidation of glucose since the energy in the coenzymes is transferred to ATP for storage.

Electron Transport Chain (Stage 3)

The electron transport chain is a series of oxidation-reduction reactions that occur on the mitochondrial cristae. This means that the coenzymes $NADH_2$ and $FADH_2$ transport their hydrogens from the mitochondrial matrix, where the reactions of the citric acid cycle takes place, to the mitochondrial cristae where the reactions of the electron transport chain take place. The reactions in the electron transport chain involve the transfer of hydrogen atoms and their electrons from weaker to progressively stronger electron acceptors.



This is a diagram of a single mitochondrion showing the location of the mitochondrial matrix and cristae. The citric acid cycle occurs in the mitochondrial matrix whereas the electron transport chain reactions occur in the mitochondrial cristae.

Most of the energy originally contained in the glucose still remains to be processed through the electron transport chain. In the mitochondrial cristae the energy in $NADH_2$ and $FADH_2$ is liberated and transferred to ATP for storage.

In the electron transport chain, four types of carrier molecules are alternately oxidized and reduced and participate in the generation of ATP:

1. the **coenzyme NAD**
2. the **coenzyme FAD**
3. a coenzyme called **coenzyme Q**, and
4. **cytochromes**, red protein pigments each of which contains an iron group.

The electron transport chain goes through the process of **oxidative phosphorylation**. It is given this name because the coenzymes $NADH_2$ and $FADH_2$ are oxidized; furthermore, their oxidation results in the production of ATP from ADP and inorganic phosphate. This process is referred to as phosphorylation. The oxidation of each $NADH_2$ in the electron transport chain generally yields 3 ATP, whereas the oxidation of each $FADH_2$ yields 2ATP. Oxidation and phosphorylation are processes that occur together in the electron transport chain.

Steps in the Electron Transport Chain

Figure 8 is a diagram of the electron transport chain. Follow the diagram as we discuss step by step the reactions of the electron transport chain.

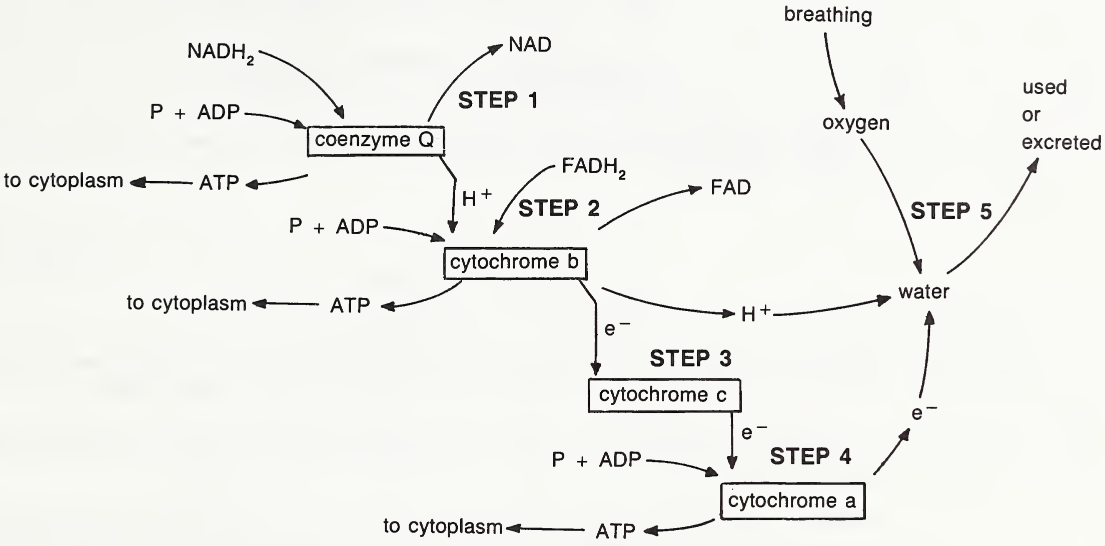


Figure 8: The Electron Transport Chain.

Step 1: The hydrogen atoms from the citric acid cycle are transferred to NAD which becomes NADH2. The hydrogen atoms carried by $NADH_2$ are then transferred to coenzyme Q. In so doing $NADH_2$ is oxidized back to NAD, while coenzyme Q is reduced. The energy released during this process is used to synthesize a molecule of ATP from ADP and inorganic phosphate.

$$\boxed{\text{ADP} + \text{P} + \text{ENERGY} \rightarrow \text{ATP}}$$

The ATP produced by this reaction is shuttled back to the cytoplasm where it can be used to promote other cellular reactions.

It is important to note that the NAD can return to the cytoplasm to participate in glycolysis reactions or it can go directly to the mitochondrial matrix to participate in the citric acid cycle.

Step 2: The hydrogens are passed from coenzyme Q to cytochrome b. At the same time the hydrogens carried by $FADH_2$ are transferred directly to cytochrome b. $FADH_2$ is oxidized back to FAD while cytochrome b is reduced. The hydrogens that are transferred to cytochrome b do not stay intact. They ionize into hydrogen ions and electrons.

$$\underset{\text{hydrogen atom}}{H} \rightarrow \underset{\text{hydrogen ion}}{H^+} + \underset{\text{electron}}{e^-}$$

The energy released by these reactions is used to synthesize more ATP from ADP and inorganic phosphate.

$$\boxed{ADP + P + ENERGY \rightarrow ATP}$$

Again, the ATP generated by these reactions is shuttled back to the cytoplasm where it can be used by the cell to promote the various reactions which require energy.

It is also important to note that FAD can return to the citric acid cycle where it can pick up hydrogens.

STEP 3: Only the electrons from hydrogen atoms are transferred from cytochrome b to cytochrome c. The hydrogen ions are used later to combine with electrons and oxygen in order to produce water which is a by-product of cellular respiration.

STEP 4: The electrons from hydrogen atoms are transferred from cytochrome c to cytochrome a. As the electrons are passed from one carrier molecule to the next, they lose energy. This energy is used to make ATP from ADP and inorganic phosphate.

$$\boxed{ADP + P + ENERGY \rightarrow ATP}$$

Again, the ATP formed by this reaction is shuttled back to the cytoplasm where the energy stored inside it can be used to initiate other cellular reactions.

STEP 5: By the time the electrons reach the end of the chain, the electrons are de-energized. At this point, they combine with hydrogen ions (H^+) and oxygen to form water. Water is a by-product of respiration.

Oxygen is the last molecule in the electron transport chain. In other words, it is the final electron acceptor. Oxygen is also the strongest electron acceptor. This oxygen, required for the complete oxidation of glucose, is supplied to your body cells through inspiration. As you know already the oxygen combines with the H^+ ions released from the breakdown of hydrogen atoms to form water. The water is either used to promote chemical reactions in cells or is excreted by the skin, kidneys, and lungs. Water is excreted by the skin in the form of sweat, by the kidneys in the form of urine, and by the lungs as water vapor.

The Importance of Oxygen in the Electron Transport Chain

Oxygen is the last molecule in the electron transport chain. In other words, it is the final electron acceptor. If there is no oxygen, the electron transport chain does not work efficiently because there is nowhere for the electrons to go. As a result, NAD is not remade from $NADH_2$. This is a problem because without NAD both glycolysis and the citric acid cycle stop, and no ATP is made.

Another unfavorable event occurs when there is a lack of NAD in the cell. The concentration of hydrogen ions increases because no carrier is available. As the quantity of H^+ in the cell increases, the pH of the cell decreases. This means that the cell becomes more acidic. If the pH of the cell becomes too low, many enzymes stop working and the cell dies. This is why many cells cannot survive without a steady supply of oxygen.

ATP Production

Let us add up the number of ATP molecules formed during the complete oxidation of glucose. During glycolysis there is a net gain of two molecules of ATP (see Figure 2). It is important to note that a total of four ATP were produced during glycolysis; however, two were used to activate glucose. This leaves a net gain of two ATP. Each molecule of glucose that is oxidized yields two molecules of pyruvic acid, both of which enter the citric acid cycle. As a result there is a production of two molecules of ATP in the citric acid cycle. The bulk of the ATP is generated in the electron transport chain, where a total of 32 ATP are produced. This ATP total is summarized as follows:

Process	**Net Gain of ATP**
Glycolysis (This process does not require oxygen)	2
Citric Acid Cycle (oxygen required)	2
Electron Transport Chain (oxygen required)	32
Total	36

The complete oxidation of a glucose molecule can be summarized as follows:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} + \underset{\substack{\text{inorganic}\\\text{phosphate}}}{36P} + \underset{\substack{\text{adenosine}\\\text{diphosphate}}}{36ADP} \rightarrow \underset{\substack{\text{carbon dioxide}\\\text{(given off}\\\text{during citric}\\\text{acid cycle)}}}{6CO_2} + \underset{\substack{\text{water}\\\text{(given off}\\\text{during electron}\\\text{transport chain)}}}{6H_2O} + \underset{\substack{\text{adenosine}\\\text{triphosphate}}}{36ATP}$$

A summary of cellular respiration is given in Figure 9. This diagram helps you to visualize exactly where the three stages of respiration take place. The total output of all three stages is 36 ATP per molecule of glucose.

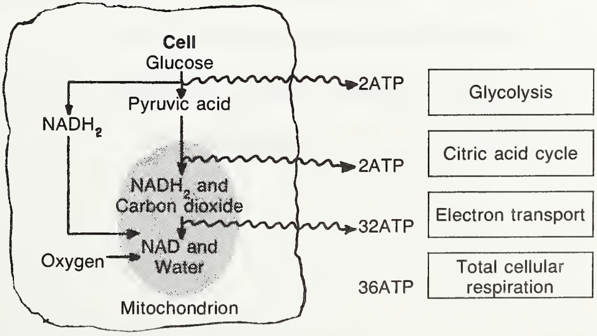


Figure 9: Summary of cellular respiration

Self-Correcting Exercise 8

Aerobic Respiration

Fill in the blanks.

1. During aerobic respiration glucose is completely oxidized in three stages:

   (a) ____________ (first stage - Anaerobic)

   (b) ____________ ____________ ____________ (second stage - Aerobic)

   (c) ____________ ____________ ____________ (third stage - Aerobic)

2. The second step is known as the ____________ ____________ cycle. It includes a series of oxidation - ____________ reactions in which coenzymes ____________ and ____________ pick up hydrogen atoms from oxidized organic acids. ____________ ATP are produced as a result of this process. The ____________ ____________ cycle is an aerobic step since it requires ____________. The citric acid cycle occurs in the matrix of the ____________. One of the by-products of the citric acid cycle is ____________ ____________ (CO_2).

3. The third step in glucose catabolism is called the ____________ ____________ chain. It includes another series of ____________ - reduction reactions, in which hydrogen atoms and in turn their electrons are passed between NAD, FAD, coenzyme ______, and the ____________. The last electron acceptor in the electron transport chain is ____________. Oxygen combines with the hydrogen ions and electrons from the electron transport chain to produce ____________ (H_2O). ____________ is a by-product of the electron transport chain. Most of the ATP is produced in the electron transport chain. There is a net yield of ____________ ATP. The electron transport chain is aerobic since it requires ____________ and it is located in the ____________ of mitochondria.

4. The three main by-products of aerobic respiration are ________________ ________________ (CO_2), ________________ (H_2O), and 36 ATP. Let us review where the by products of aerobic respiration comes from:

(a) Glycolysis yields __________ ATP.

(b) Citric Acid Cycle yields __________ ATP and ________________ ________________.

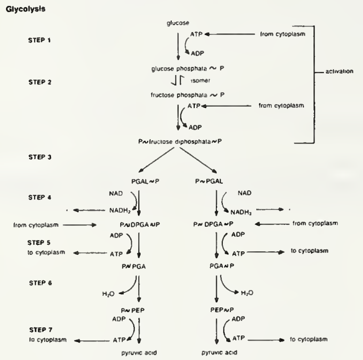
(c) Electron Transport Chain yields __________ ATP and ________________.

Check your answers with those on pages 38 and 39. Correct any errors that you may have.

A Detailed Look at ATP Production for the Complete Oxidation of Glucose

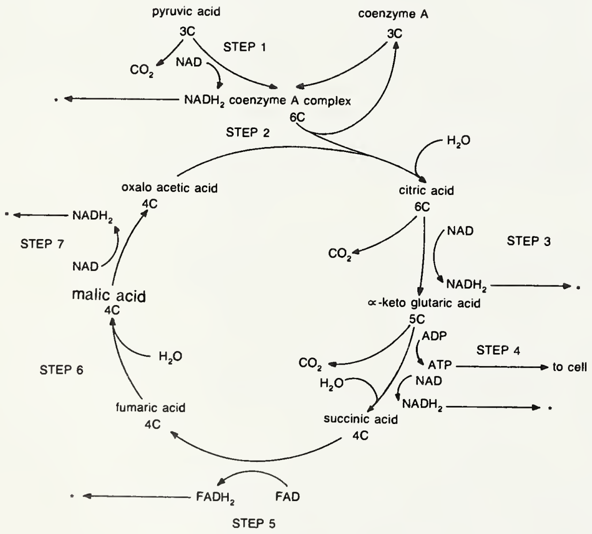
Let us review the reaction sequence for **glycolysis**, the **citric acid cycle**, and the **electron transport chain** for the purpose of adding up the ATP produced. In this way you can see step by step exactly where the ATP was derived.

1.



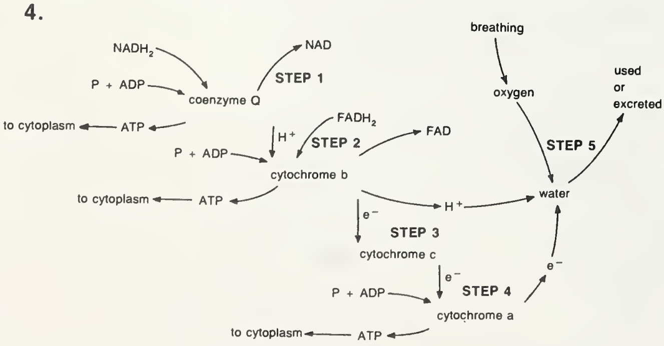
2.

3.



*transferred to the electron transport chain located in the cristae of the mitochondria.

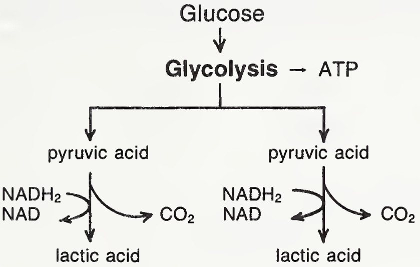
4.



1. **Reaction Sequence**	**ATP yield per glucose**
Glycolysis: (occurs in the cytoplasm)	
phosphorylation of glucose	− 1
phosphorylation of fructose phosphate	− 1
dephosphorylation of 2 molecules of DPGA	+ 2
dephosphorylation of 2 molecules of PEP to form 2 molecules of pyruvic acid	+ 2
*The 2NADH$_2$ formed in the oxidation of 2 molecules of PGAL are transported from the cytoplasm to the mitochondrial cristae. The ATP derived from NADH$_2$ will be accounted for in the electron transport chain.	
2. **Conversion of 2 molecules of Pyruvic Acid to Acetyl Coenzyme A (acetyl CoA)**	
(occurs inside the mitochondria) *2 NADH$_2$ are formed in the oxidative decarboxylation of pyruvic acid. The 2NADH$_2$ are transported to the electron transport chain; therefore, the ATP derived from NADH$_2$ will be accounted for in the electron transport chain.	
3. **Citric Acid Cycle**	
(occurs in the mitochondria) Formation of 2 molecules of succinic acid from 2 molecules of ketoglutaric acid.	+ 2
*6NADH$_2$ are formed in the oxidation of 2 molecules of citric acid, ketoglutaric acid, and malic acid. The ATP derived from this reaction will be accounted for in the electron transport chain.	
*2FADH$_2$ are formed in the oxidation of 2 molecules of succinic acid. The ATP derived from this reaction will be accounted for in the electron transport chain.	
4. **Electron Transport Chain**	
*2NADH$_2$ formed in glycolysis each yields 2ATP (not 3ATP each because of the energy used up to shuttle the NADH$_2$ from the cytoplasm to the electron transport chain in the mitochondria).	+ 4
*2NADH$_2$ formed in the conversion of pyruvic acid to acetyl coenzyme A (i.e. oxidative decarboxylation of pyruvic acid). Each NADH$_2$ yields 3ATP.	+ 6
*6NADH$_2$ formed in the citric acid cycle; each yields 3ATP.	+18
*2FADH$_2$ formed in the citric acid cycle; each yields 2ATP.	+ 4
Net Yield per Glucose	**+36**

A Comparison of Anaerobic and Aerobic Respiration

Anaerobic Respiration

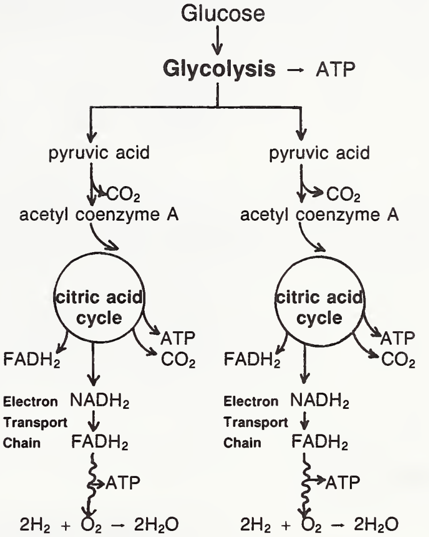


1. The process of anaerobic respiration does not require oxygen.

2. Anaerobic respiration takes place in the cytoplasm of muscle cells. Skeletal muscles tend to utilize glucose anaerobically. Glucose breaks down into lactic acid during the process of glycolysis. On the other hand, heart muscle does not normally form lactic acid from glucose; it oxidizes pyruvic acid to carbon dioxide and water aerobically.

3. End products of Anaerobic Respiration: Lactic Acid, 2ATP.

Aerobic Respiration



1. The process of aerobic respiration requires oxygen.

2. Aerobic respiration takes place in the mitochondria of the cells (excluding muscle cells).

3. End products of Aerobic Respiration: Carbon Dioxide (CO_2), Water (H_2O), 36 ATP

Equation Representing the Complete Oxidation of Glucose

In the human body carbohydrates (i.e. glucose) serve as a fuel and are oxidized to carbon dioxide and water by aerobic respiration. During this process energy is liberated and eventually trapped inside ATP molecules. The overall equation for the complete oxidation of glucose (aerobic respiration) is given below:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} + \underset{\text{inorganic phosphate}}{36P} + \underset{\text{adenosine diphosphate}}{36ADP} \rightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{adenosine triphosphate}}{36ATP}$$

Let us summarize what happens during aerobic respiration without a detailed discussion of the three stages: glycolysis, citric acid cycle, and the electron transport chain. Refer to the above equation as you read the next paragraph. Glucose ($C_6H_{12}O_6$) becomes oxidized, not by a gain of oxygen, but by a loss of hydrogens and their electrons. The hydrogens and their electrons are passed to oxygen which becomes reduced. This results in the formation of water. The glucose without its hydrogens yields carbon dioxide. The energy released during this process is trapped inside ATP molecules. ATP molecules are formed by the addition of ADP, inorganic phosphate, and energy.

Uses of ATP

1. Active Transport

Active transport is the process by which substances (usually ions), are transported across plasma membranes from an area of lower concentration to an area of higher concentration. In other words, the energy from ATP is used to transport molecules against the concentration gradient. One example of this is that ATP is needed to maintain water balance in the cells of the kidneys. With the help of ATP, water molecules may be transported in or out of kidney cells to bring about a steady state.

2. The Contraction of a Muscle

The contraction of a muscle requires energy. When a nerve impulse stimulates a muscle fibre, ATP, in the presence of an enzyme breaks down into ADP and inorganic phosphate and energy is released.

Nerve cells perform electrical work and here again ATP aids the movement of ions (charged particles) across the plasma membrane, thus generating an electrical potential. The generation and conduction of electrical charge is the basis of neural transmission. If ATP molecules were poisoned by nerve gas, paralysis would occur because electrical impulses could not be generated.

3. Synthesis of Organic Molecules

The synthesis of proteins, polysaccharides, and nucleic acids cannot proceed without the input of energy from ATP.

4. Heat Production

Most of the energy generated during cellular respiration is stored in ATP molecules until it is needed for cellular processes. Some energy is released in the form of heat.

All metabolic activities that require ATP also produce heat. In this case, heat energy escapes as ATP transfers its energy to power these metabolic processes. You feel this when you become warm during strenuous exercise. Sometimes this extra heat is helpful to man in maintaining a constant body temperature (37°C). Similarly the heat produced by cells may help them to function properly. On the other hand, this extra heat can be harmful. For example, it can make you feel nauseous.

Self-Correcting Exercise 9

Fill in the blanks.

1. The energy derived from the complete oxidation of glucose is stored in ATP until it is needed by the cells for cellular activities. List four ways in which ATP can be used by cells:

(a) ____________________

(b) ____________________

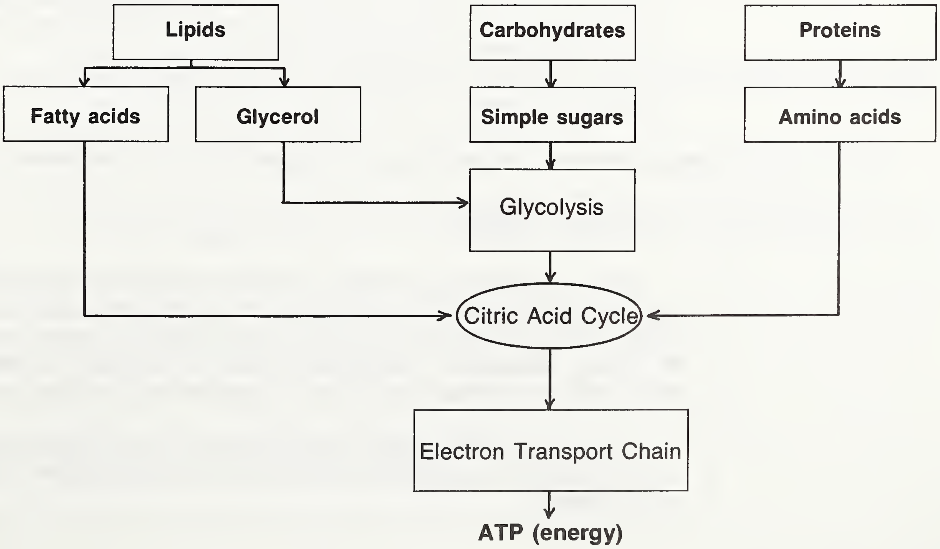
(c) ____________________

(d) ____________________

Check your answers with those on page 39. Correct any errors in your work.

Other Pathways

Proteins and lipids are oxidized in very much the same way as glucose. However, the intermediate products vary slightly and the total amount of ATP produced as a result of the oxidation of proteins and lipids are slightly different from that of glucose. The difference in ATP depends very much on the type of lipid or protein being oxidized. Another difference is that lipids and proteins enter the glycolytic and citric acid cycle pathways at different points. The diagram below illustrates some of these facts.



Cells obtain roughly the same amount of energy per gram from proteins and carbohydrates. Lipids, on the other hand, yield twice as much energy per gram as do carbohydrates or proteins. The energy yield from carbohydrates and proteins is about 4 cal/g. Fats yield about 9 cal/g.

Self-Correcting Exercise 10

Fill in the blanks and answer the questions.

1. Most of the energy generated in cellular ________________ is stored in molecules of ________________. Some of the energy is released in the form of ________________.

2. The heat produced by metabolic processes can be used to

   (a) ____

   ____

   ____

   (b) ____

   ____

   ____

   (c) ____

   ____

   ____

3. Glucose is not the only nutrient oxidized by the cells of your body. Cells also oxidize ________________ and ________________ in very much the same way as glucose (carbohydrates). Cells obtain about the same amount of energy per gram from proteins and ________________. However, ________________ yield twice as much energy per gram as the other two nutrients.

Check your answers with those on page 39. Correct any errors in your work.

**** Attention Students**

Please note that you are not required to memorize the detailed steps involved in aerobic respiration (i.e. glycolysis, citric acid cycle, electron transport chain). These detailed steps were included in this lesson to enrich your understanding of cellular respiration. Furthermore, you do not have to memorize chemical formulas for the various products and intermediate products of aerobic respiration.

If you have successfully completed the self-correcting exercises as well as the exercises to be sent in for correction, you have fulfilled the main objectives of this lesson.

ANSWERS TO THE SELF-CORRECTING (KEYED) EXERCISES

Self-Correcting Exercise 1, p. 3

1. The main source of energy from food is derived by the **breaking** of bonds. The breaking of bonds within food molecules takes place in **cells**. The energy released by the oxidation of food molecules is stored in molecules of **ATP**.

2. All normal cells are capable of **metabolizing or oxidizing** glucose.

3. During cellular respiration the energy from food is converted to a more usable form of energy called **ATP**.

4. The word metabolism refers to the sum of all **catabolic (decomposition)** and **anabolic (synthesis)** reactions. When we say that a person has a high **metabolism**, we mean that the chemical reactions in the cells are proceeding at a faster rate than normal.

5. Reactions where hydrogen atoms are lost are known as **oxidation** reactions. Reactions where hydrogen ions and **electrons** are gained are known as **reduction** reactions. These reactions occur in pairs. Hydrogen acceptors in cells are referred to as **coenzymes**.

Self-Correcting Exercise 2, p. 6

1. ATP stands for **adenosine triphosphate**.

2. List the three components of ATP:
   (a) **adenine**
   (b) **ribose**
   (c) **phosphates or phosphate groups**

3. ATP is a complex molecule. Adenosine is one of its components. Adenosine is composed of the molecules **adenine** and **ribose**. Attached to the adenosine molecule are three **phosphate** groups.

4. What do we mean by the term "high-energy bond"?
   A high energy bond (~) is one which releases more energy when broken than a normal bond (–).

5. ATP may be synthesized in the cell by adding **phosphate** and **energy** to ADP.

6. ATP can decompose into ADP and **phosphate** by the process of **hydrolysis**. This is an energy **yielding** reaction.

Self-Correcting Exercise 3, p. 7-8

1. Polysaccharides and disaccharides are broken down into **monosaccharides** by the process of **hydrolysis**.

2. Glucose, fructose, and galactose are monosaccharides which are absorbed into the villi of the small intestine and transported by the blood stream to the **liver**. Here the monosaccharides are converted to **glucose**. Thus the story of carbohydrate metabolism is really the story fo glucose metabolism.

3. **Glucose** is the body's major source of energy.

4. When the cells require energy, glucose is **metabolized or oxidized**.

5. When the cells do not require glucose immediately, the body has three basic ways of processing it:

   (a) **Glucose is converted to glycogen by the liver. Glycogen is stored in the liver and muscle cells.**

   (b) **If the glycogen storage areas are filled, the liver converts excess glycogen to fat.**

   (c) **Excess glucose is secreted in the urine. This condition is called glycosuria.**

6. What do you think would happen to cells if all of the energy in glucose were utilized at once during the process of carbohydrate metabolism? Explain.
   The cells would not be able to use the energy all at once. The excess energy given off in the form of heat would probably damage cells beyond repair.

Self-Correcting Exercise 4, p. 10

1. The oxidation of glucose is also known as **cellular respiration.**

2. When glucose enters the cytoplasm of cells it is immediately **phosphorylated** with the addition of a phosphate group.

3. The phosphorylation of glucose enables the molecule to
   (a) **become trapped inside the plasma membrane of cells.**
   (b) **become activated or more chemically reactive.**

4. Cellular respiration occurs in three successive stages:
   (a) **glycolysis**
   (b) **citric acid cycle**
   (c) **electron transport chain**

5. What do you think would happen to your body if phosphorus was eliminated from your diet? (Good sources of phosphorus are dairy products, meat, fish, poultry, nuts).
   (a) **Your bones and teeth would become brittle. (general knowledge)**
   (b) **Your cells would have difficulty metabolizing food.**
   (c) **Energy could not be derived from food. Therefore energy is not available to promote cellular activity.**
   (d) **Energy could not be stored in molecules of ATP.**

Self-Correcting Exercise 5, p. 13

1. Glycolysis is a series of chemical reactions which are catalyzed by specific enzymes. Glycolysis occurs in the **cytoplasm** of cells.

2. During glycolysis, glucose is converted to two molecules of **pyruvic acid**.

3. The total number of ATP formed by glycolysis is **four** ATP. Two of these were used to activate glucose. This leaves a net energy gain of **two** ATP.

4. What factors do you think would inhibit the process of glycolysis?
   (a) **Lack of phosphorus in the diet would cause glucose to remain inactive. Thus it could not be utilized by cells to produce energy. A lack of phosphorus in the diet would also cause difficulty in nerve transmission.**
   (b) **Destruction of ATP molecules by toxins causes glucose to remain inactive. This is because the phosphate from ATP would not be available to activate glucose by phosphorylation.**
   (c) **The cytoplasm of the cells could be too acidic or too basic to promote the reactions glycolysis.**

Self-Correcting Exercise 6, pp. 17-18

1. During glycolysis **glucose** is converted to two molecules of **pyruvic acid**. The fate of pyruvic acid depends on the availability of **oxygen.**

2. When oxygen is not available (anaerobic conditions), pyruvic acid is reduced to **lactic acid**. Anaerobic respiration occurs in the **cytoplasm** of muscle cells.

3. When oxygen is available (aerobic conditions), pyruvic acid is oxidized to **carbon dioxide** and **water**. Aerobic respiration occurs in the **mitochondria** of body cells.

4. The three stages of aerobic respiration are:
   (a) **glycolysis**
   (b) **citric acid cycle**
   (c) **electron transport chain**

5. Anaerobic respiration occurs in two basic stages:
   (a) **glycolysis**
   (b) conversion of pyruvic acid to lactic acid

6. The accumulation of lactic acid in muscle cells, during anaerobic conditions, is a result of **oxygen** debt. A large amount of lactic acid in muscle cells causes muscle **fatigue**.

7. After strenuous exercise, the muscle is said to have incurred an oxygen debt. This debt is repaid by breathing **rapidly** and **deeply**. As oxygen enters the muscle cells, lactic acid leaves. Lactic acid is transported by the circulatory system to the **liver** where it is converted back to **glycogen (glucose).**

8. What do you think would happen to your body if it did not have a homeostatic mechanism for reducing the amount of lactic acid build up in the muscle cells?
   The extracellular fluid would become too acidic and destroy the cells and eventually the entire body.

Self-Correcting Exercise 7, pp. 19-20

1. Aerobic respiration has three basic stages:
   (a) **glycolysis**
   (b) **citric acid cycle**
   (c) **electron transport chain**

2. Pyruvic acid was formed at the end of glycolysis. When enough oxygen is available (aerobic conditions), pyruvic acid is prepared to enter the **citric acid cycle**.

3. Pyruvic acid is converted to **acetyl coenzyme A** in the mitochondria of cells. Pyruvic acid is converted to **acetyl coenzyme A** by the loss of **carbon dioxide** (decarboxylation) and the addition of coenzyme A. Once pyruvic acid is converted to **acetyl coenzyme A**, it can enter the citric acid cycle.

4. A series of molecules called **enzymes** are used to catalyze reactions in both the anaerobic and aerobic phase of respiration. These molecules are **protein** in nature.

5. Coenzymes work together with **enzymes**. Instead of catalyzing reactions as **enzymes** do, coenzymes act as carrier molecules. Three examples of coenzymes are
   (a) **coenzyme A**
   (b) **NAD**
   (c) **FAD**

Self-Correcting Exercise 8, pp. 28-29

Aerobic Respiration

1. During aerobic respiration glucose is completely oxidized in three stages:
   (a) **glycolysis** (first stage - Anaerobic)
   (b) **citric acid cycle** (second stage - Aerobic)
   (c) **electron transport chain** (third stage - Aerobic)

2. The second step is known as the **citric acid** cycle. It includes a series of oxidation - **reduction** reactions in which coenzymes **NAD** and **FAD** pick up hydrogen atoms from oxidized organic acids. **Two** ATP are produced as a result of this process. The **citric acid** cycle is an aerobic step since it requires **oxygen**. The citric acid cycle occurs in the matrix of the **mitochondria**. One of the by products of the citric acid cycle is **carbon dioxide** (CO_2).

3. The third step in glucose catabolism is called the **electron transport** chain. It includes another series of **oxidation** - reduction reactions, in which hydrogen atoms and in turn their electrons are passed between NAD, FAD, coenzyme **Q**, and the **cytochromes**. The last electron acceptor in the electron transport chain is **oxygen**. Oxygen combines with the hydrogen ions and electrons from the electron transport chain to produce **water** (H_2O). **Water** is a by product of the electron transport chain. Most of the ATP is produced in the electron transport chain. There is a net yield of **32** ATP. The electron transport chain is aerobic since it requires **oxygen** and it is located in the **inner membranes or cristae** of mitochondria.

4. The three main by products of aerobic respiration are **carbon dioxide** (CO_2), **water** (H_2O), and 36 ATP. Let us review where the by products of aerobic respiration comes from:
   - (a) Glycolysis yields **two** ATP.
   - (b) Citric Acid Cycle yields **two** ATP and **carbon dioxide** (CO_2).
   - (c) Electron transport chain yields **32** ATP and **water** (H_2O).

Self-Correcting Exercise 9, p. 33

1. The energy derived from the complete oxidation of glucose is stored in ATP until it is needed by the cells for cellular activities. List four ways in which ATP can be used by cells:
   - (a) **active transport**
   - (b) **contraction of muscles by neural transmission**
   - (c) **heat production**
   - (d) **synthesis of organic molecules**

Self-Correcting Exercise 10, p. 34

1. Most of the energy generated in cellular **respiration** is stored in molecules of **ATP**. Some of the energy is released in the form of **heat**.

2. The heat produced by metabolic processes can be used to
   - (a) **maintain constant body temperature**
   - (b) **help cells to function properly**
   - (c) **make you feel nauseous (sick)**

3. Glucose is not the only nutrient oxidized by the cells of your body. Cells also oxidize **lipids (fats)** and **proteins** in very much the same way as glucose (carbohydrates). Cells obtain about the same amount of energy per gram from proteins and **carbohydrates**. However, **lipids (fats)** yield twice as much energy per gram as the other two nutrients.

EXERCISES TO BE SENT IN FOR CORRECTION

Exercise 1 Multiple Choice

Choose the best answer and write the appropriate letter in the blank provided.

______ 1. The greatest amount of energy is released by the

(a) oxidation of glucose to lactic acid
(b) oxidation of glucose to carbon dioxide and water
(c) conversion of glucose to pyruvic acid
(d) conversion of carbon dioxide and water to glucose

______ 2. In aerobic respiration, the final hydrogen (electron) acceptor is

(a) water
(b) molecular oxygen
(c) carbon dioxide
(d) cytochrome a

______ 3. Pyruvic acid must be converted to ____________ before it can enter the citric acid cycle.

(a) lactic acid
(b) ketoglutaric acid
(c) $NADH_2$
(d) acetyl coenzyme A

______ 4. Which of the following parts of the cell is the site of most respiratory enzymes?

(a) nucleus
(b) endoplasmic reticulum
(c) mitochondria
(d) cell membrane

______ 5. During energy transfer, hydrogen and its electrons move from

(a) $NADH_2$ to ATP in the electron transport chain
(b) ATP to $FADH_2$ in the electron transport chain
(c) weak to progressively stronger electron acceptors in the electron transport chain
(d) strong to progressively weak electron acceptors in the electron transport chain

______ 6. ATP is formed during energy transfer when

(a) energy is released as electrons are transferred to various electron acceptors
(b) $NADH_2$ is formed
(c) hydrogen is added to oxygen to produce water
(d) $FADH_2$ and coenzyme A are formed

______ 7. The total amount of ATP formed by aerobic respiration is

(a) 2 ATP
(b) 4 ATP
(c) 36 ATP
(d) 32 ATP

______ 8. Aerobic respiration involves the process(es) of

(a) glycolysis
(b) electron transport chain
(c) citric acid cycle
(d) all of the above

______ 9. Both anaerobic and aerobic respiration

(a) use CO_2 as a raw material (reactant)
(b) liberate carbon dioxide and oxygen
(c) form ATP through the cytochrome enzyme system
(d) liberate energy from glucose

______ 10. Glycolysis takes place in the ____________ of cells.

(a) mitochondrial cristae
(b) mitochondrial matrix
(c) cytoplasm
(d) nucleus

______ 11. The carbon containing compounds formed at the end of glycolysis are two molecules of

(a) carbon dioxide
(b) pyruvic acid
(c) lactic acid
(d) citric acid

______ 12. Muscle fatigue and cramps are caused by an accumulation of

(a) ADP.
(b) citric acid.
(c) pyruvic acid.
(d) lactic acid.

______ 13. While a cell is in the process of reducing (''repaying'') an oxygen debt

(a) lactic acid is converted to glycogen (glucose) by the liver
(b) glucose acts as an oxygen acceptor
(c) pyruvic acid is converted to lactic acid
(d) $NADH_2$ acts as an oxygen acceptor

______ 14. In comparison with aerobic respiration, anaerobic respiration

(a) requires oxygen and releases less energy
(b) requires oxygen and releases more energy
(c) does not require oxygen and releases less energy
(d) does not require oxygen and releases more energy

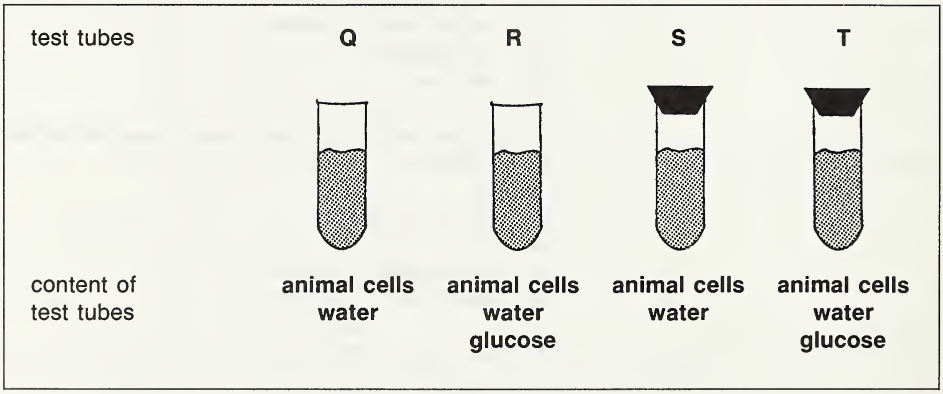
______ 15. The greatest number of adenosine triphosphate (ATP) molecules are produced during respiration when the end product is

(a) water
(b) oxygen
(c) acetyl coenzyme A complex
(d) pyruvic acid

______ 16. Aerobic and anaerobic respiration are similar in that they both

(a) liberate energy from glucose
(b) produce O_2 as a waste product
(c) result in the accumulation of lactic acid
(d) utilize cytochrome b as a final electron acceptor

Use the following information to answer question 17.



______ 17. Overtime, total adenosine triphosphate (ATP) production will be greatest in test tube

(a) Q
(b) R
(c) S
(d) T

______ 18. The anaerobic breakdown of glucose in muscle tissue results in

(a) a high yield of energy
(b) the formation of lactic acid
(c) the formation of H_2 and CO_2
(d) the release of energy in the citric acid cycle

______ 19. Which of the following acts as a phosphate donor in cellular respiration?

(a) ATP
(b) cytochromes
(c) lactic acid
(d) ADP

______ 20. When a muscle becomes fatigued there is

(a) little or no ATP, little glycogen, and much lactic acid
(b) a depletion of water from the muscle
(c) much lactic acid, much ATP, and much glycogen in the muscle
(d) a build up of adenosine triphosphate (ATP) in the muscle

______ 21. During metabolism, glucose molecules are activated by

(a) lactic acid
(b) the addition of oxygen
(c) cytochromes
(d) the addition of a phosphate group from ATP

______ 22. The breathing rate of a runner who finishes a 1000 m race remains quite high for a period of time. This rapid breathing rate is because of

(a) the accumulation of citric acid in the muscle
(b) the oxygen debt
(c) hyperventilation
(d) carbon dioxide deprivation

______ 23. Before glucose can be utilized in cellular respiration, the glucose molecule must undergo

(a) phosphorylation
(b) dehydrogenation (removal of hydrogens)
(c) decarboxylation
(d) dehydration (removal of water)

______ 24. In addition to glucose, energy sources that cells may use are

(a) salts and proteins
(b) minerals and salts
(c) proteins and fats
(d) fats and vitamins

______ 25. An oxygen debt in muscle tissue results in the

(a) catabolism (breakdown) of lactic acid
(b) accumulation of lactic acid
(c) catabolism (breakdown) of citric acid
(d) accumulation of pyruvic acid

______ 26. Which of the following might illustrate the conversion that supplies the required energy for muscle contraction?

(a) pyruvic acid + H_2 → lactic acid
(b) glucose → CO_2 + lactic acid
(c) Adenosine triphosphate (ATP) → Adenosine diphosphate (ADP) + phosphorus (P)
(d) Adenosine diphosphate (ADP) → adenosine triphosphate (ATP)

Exercise 2

Fill in the blanks.

1. The main source of energy from food is derived by the ______________ of bonds in the cells. The energy released is in small packets known as ______________. The bonds in food molecules are broken by a series of reactions each catalyzed by an ______________.
2. Respiration and breathing are not the same thing. Breathing provides the ______________ necessary for ______________ respiration. Oxygen is not required for ______________ respiration.
3. ATP may be synthesized in the cell by adding ______________ and ______________ to ADP.
4. The energy needed to phosphorylate ADP comes from the metabolism of ______________.
5. The raw materials (reactants) of aerobic respiration are ______________, ______________, 36 ADP and 36 ______________.
6. The end products of aerobic respiration are ______________ ______________, ______________, and 36 ______________.

7. The three stages of aerobic respiration are

(a) ____

(b) ____

(c) ____

Most events in aerobic respiration take place in the ______________ of cells.

8. Anaerobic respiration includes glycolysis and the conversion of ______________ acid into ______________ acid which accumulates in the muscle cells. Glycolysis takes place in the ______________ of the cell.

9. Muscle fatigue is caused by the build up of ______________ acid and ______________ ______________ in the muscle cells.

10. The two ATP formed during aerobic respiration come from ______________. The remaining ATP come from the ______________ ______________ cycle and the ______________ ______________ chain. There is a total of ______________ ATP formed during aerobic respiration.

11. What is the name of the coenzyme used in glycolysis to transport hydrogen atoms to the electron transport chain?

____

12. What are the names of the coenzymes used in the citric acid cycle to transport hydrogen atoms to the electron transport chain? ______________ and ______________

13. The last electron acceptor in the electron transport chain is ______________.

14. The strongest electron acceptor is (NAD/FAD/O_2). Circle the correct answer.

Exercise 3 Short Answer

1. What is the difference between cellular respiration and breathing?

____

____

____

2. Name the two places in the cell where cellular respiration takes place:

_______________ and _______________

3. What role do enzymes play in cellular respiration?

____

____

____

4. What role do coenzymes play in cellular respiration?

____

____

____

5. List three (3) physiological processes that require energy from ATP.

(a) ______________________________

(b) ______________________________

(c) ______________________________

6. What must happen to glucose before it can be used in the process of cellular respiration?

____

____

____

7. What happens to glucose during glycolysis?

____

____

____

8. During glycolysis more than two molecules of ATP is produced from each molecule of glucose. Why are two molecules of ATP considered the net yield of glycolysis?

9. What is the function of molecular oxygen, O_2, in cellular respiration?

10. Write a single chemical equation to show how ATP is formed from ADP.

11. Define:

(a) oxidation

(b) reduction

12. Given the equation:

$$NADH_2 + FAD \rightarrow FADH_2 + NAD$$

(a) What is being oxidized?

(b) What is being reduced?

13. How do we build up an "oxygen debt"?

14. What substance accumulates in fatigued muscles?

____

15. How do we ''repay'' our oxygen debt?

____

____

____

Please submit pages 40 to 48 for correction.

END OF LESSON 6

LESSON RECORD FORM

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1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
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(4) The Lesson Record Form is filled out and the correct lesson label is attached.
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2. POSTAGE REGULATIONS

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Send all letters in a separate envelope.

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Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

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When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

OBJECTIVES

At the conclusion of this lesson you should be able to:

A. The Skeletal System

1. **List** the general functions of the skeletal system.
2. **Differentiate** between the appendicular and axial skeleton.
3. **Describe** how bone is formed.
4. **Be familiar with** the structure and functions of the following tissues - cartilage, bone, ligaments and tendons.
5. **Understand** the differences between compact and spongy bone.
6. **List** the types of joints and explain how they work.
7. **Explain** the differences between ligaments and tendons.
8. **Describe** the specialized structure of the skull (plates of bone joined by sutures).
9. **Identify** the five regions of the vertebral column and explain the differences in structure and function of the vertebrae in each region.
10. **Recognize** the value of the intervertebral discs and problems arising from slipped discs.
11. **Identify** the three parts of the pelvis and explain the physical differences between the pelvis of males and females.
12. **Be familiar with** the parts of the upper and lower limbs, paying particular attention to the hands and feet.
13. **Be familiar with** skeletal injuries and disease.
14. **Describe** the structure of bone.
15. **Explain** the function of synovial fluid in movable joints.
16. **Differentiate** between red and yellow marrow in bone.
17. **Describe** the importance of the Haversian canals.
18. **Relate** the importance of proper diet to proper bone development.

B. The Muscular System

1. **Differentiate** among the terms skeletal, smooth and cardiac muscle.
2. **Describe** the differences in the structure and function among the three muscle types.

3. **Explain** how muscle contraction and expansion works.
4. **Describe** the structure of skeletal muscle, applying this knowledge to their contractile actions.
5. **Explain** how nervous stimulation leads to muscle contraction.
6. **Understand** the energy needs of the muscle cell - ATP or creatine phosphate.
7. **Differentiate** between isometric and isotonic contraction.
8. **Explain** the need for antagonistic pairs of muscles.
9. **Describe** how muscles are attached to bone and know the meaning of the terms ''origin'' and ''insertion.''
10. **Understand** the structure and function of bursae and describe the condition known as bursitis.
11. **List** examples of bones that act as different classes of levers.
12. **Explain** the causes and general symptoms of muscle fatigue.
13. **Define** the term ''muscle tone'' and explain how this influences good posture.
14. **Know** the terminology of muscle movements, i.e. flexion, extension, adduction, abduction and rotation.
15. **Describe** muscle disorders such as muscular dystrophy, paralysis and muscle spasms.

HUMAN SKELETON AND MUSCLES

Introduction

Movement depends upon the contraction of the muscles against the skeleton. The human skeleton provides protection and support as well as a system of levers. Muscles are attached to the bones by tendons and provide the power to move the skeletal parts.

Bone is a living organ system which stores calcium and phosphorus and forms red blood cells. **Cartilage** is another tissue in the articulating skeletal system. **Ligaments** connect bone to bone.

There are about 206 bones in the body. These bones can be classified as long, short, flat or irregular. Their shape mirrors their function, for example, long bones for movement of the arms and legs, short bones for the movement of the wrist and ankle and flat bones for the protection of the skull.

The more than 600 muscles of the body are responsible for movement and can be classified as skeletal, cardiac or smooth muscle. When we run, jump or walk we are using **skeletal muscles**. The heart is composed of **cardiac muscles** which constantly contract and relax, supplying blood to all parts of the body. The stomach and intestine (viscera) are made of **smooth muscle**.

After being stimulated by the nervous system the muscle proteins, **actin** and **myosin,** slide past each other, contracting the muscle and producing heat. Muscles can "pull" but cannot "push" and so they work in opposite or antagonistic pairs in order to effect movement.

The Structure of Bone and Bone Formation

READ

Read the section in your textbook entitled "The Skeletal System" (pp. 85 to 88).

The human skeleton is made of two tissues: bone and cartilage. **Cartilage** is a more flexible tissue than bone and forms the end of our nose and shapes our ears. It also lines and cushions joints (articular cartilage). Our skeleton is laid down in cartilage while we are in the uterus. As we grow the cartilage is gradually replaced by bone.

Bone formation is called **ossification** and starts as early as the second fetal month for some bones. This will continue until we are about 20. The process proceeds as follows:

1. Calcium salts are deposited in about the middle of the cartilage model of bone.
2. The **periosteum** lays down a collar of spongy bone through the activation of bone cells or **osteocytes**.
3. The developing bone receives a blood supply. Bone marrow begins to form and bone is laid down in **concentric** circles around the blood supply (Haversian system).

4. Secondary centres of ossification form at either end of the bone as it develops.
5. Secondary growth centres are replaced by epiphyseal plates which are active and allow for the elongation of bone during childhood. These are under the control of pituitary and sex hormones.
6. Epiphyseal plates disappear, growth is complete and blood vessels of the epiphysis and diaphysis interconnect. Articular cartilage often covers the end of the bone.

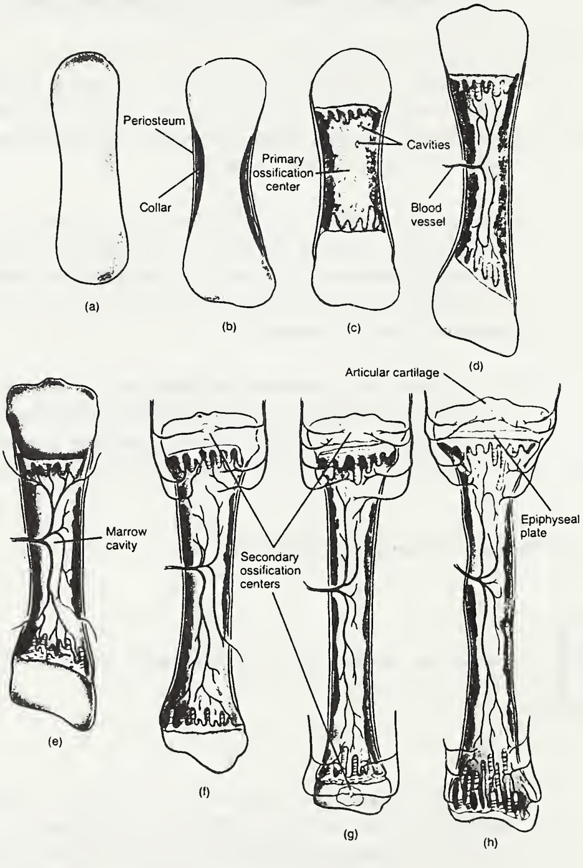


Figure 1: Ossification of the tibia. A. Cartilage model. B. Collar formation. C. Developing primary ossification centre. D. Extrance of blood vessels. E-G. Formation of marrow cavity and secondary ossification centres. H. Articular cartilage and epiphyseal plate formation.

Exercise 1

Match the structure on the right with the description on the left.

______ flexible, rubbery support tissue

______ ground substance containing calcium and phosphorus

______ little blood canals

______ porous light bone

______ soft bone centre producing red blood cells

______ tough membrane producing bone cells

______ bone cells

______ soft bone centre storing fat

______ cartilage plate allowing growth

______ blood vessel system supplying bone with nutrients

A. spongy bone

B. compact bone

C. periosteum

D. red bone marrow

E. yellow bone marrow

F. cartilage

G. osteocytes

H. matrix

I. canaliculi

J. Haversian canals

K. epiphysial plate

Please check your work with the answers given on page 16.

Organization of the Skeleton

READ

Read the section of your textbook entitled "The Skeleton" (pp. 88 to 104).

The skeleton is commonly considered to consist of two divisions:

(a) the axial skeleton - head, hyoid bone, vertebral column, sternum and ribs.

(b) the appendicular skeleton - arms and legs plus pectoral and pelvic girdles.

The Axial Skeleton

The **skull** is formed of immoveable bones and the moveable lower jaw or mandible. There are 8 bones in the cranium surrounding the brain. These are joined at immoveable joints called **sutures**. During the early development of the brain there are spaces between the bones called **fontanels** which are covered by a membranous tissue (see Figure 2). These spaces allow for movement during birth and for the development of the brain. The anterior fontanel is the most noticeable and is usually known as the "soft spot" on the baby's head.

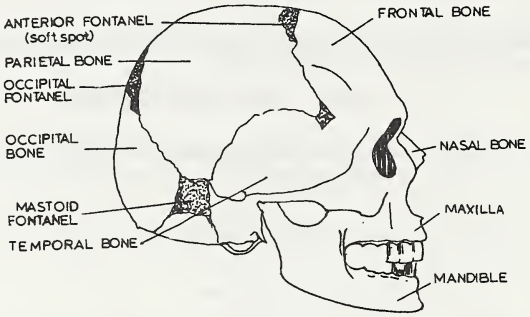


Figure 2: Skull of a newborn infant showing bone development and fontanels

READ

Refer to your textbook for the location and function of the following cranial bones:

frontal
parietal
occipital
temporal
sphenoid
ethmoid

The bones of the face, **facial bones,** are all paired except for the mandible. Using your text, locate the nasal bones, maxilla and zygomatic bones. The mandible articulates with the temporal bone by means of the coronoid process.

You should also know the location and function of two large holes in the skull; the **auditory meatus** through which sound passes to the middle ear and the **foramen magnum** where the nerve cord enters the skull.

Exercise 2

Part One: Fill in the Blanks

1. The axial skeleton consists of bones of the ______________, hyoid, ______________ column, sternum and ______________.

2. The moveable part of the skull is the ______________________ .

3. There are ______________ cranial bones joined at immoveable joints called ______________. The spaces between bones in the developing child are called ________________________.

4. The ____________ bones protect the organs of sight, hearing and smell.

Part Two: Matching

Match the structure on the right with the description on the left.

______	"cheek bones"	A. frontal
______	bone of the forehead	B. parietal
______	immoveable jaw bone	C. occipital
______	opening for inner ear	D. temporal
______	bone containing foramen magnum	E. nasal bones
______	bones on side of skull beside the ears	F. maxilla
______	bones of bridge of nose	G. zygomatic bones
______	skull bones on top and side of head	H. auditory meatus

Please check your work with the answers give on pages 16 and 17.

The **vertebral column** is made of 26 individual bones called **vertebrae**. These are divided into five regions with 7 cervical, 12 thoracic, 5 lumbar, (5 fused) sacral, and (4 fused) coccyx vertebrae.

The two functions of the vertebral column or backbone include the support of the trunk and protection of the spinal cord. There are variations in the vertebra from the different regions but in general they consist of a **body**, to support the weight of the trunk and an **arch** forming the vertebral foramen through which the spinal cord passes. Each vertebra also has a number of processes which project laterally and dorsally for the attachment of muscles. (Run your finger down your spine to feel the spinous processes of your vertebrae.) Where vertebrae articulate with one another, or other bones, there are **facets** covered with cartilage. Refer to your textbook for the vertebral differences in each region of the backbone (pp. 93-98).

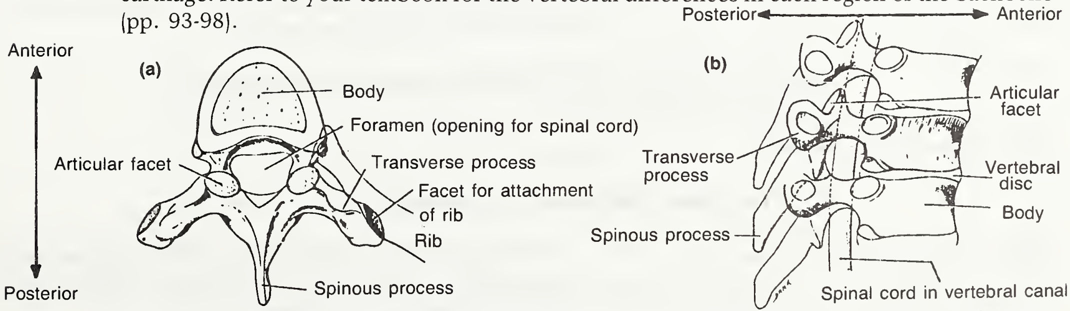


Figure 3: Thoracic vertebrae (a) Dorsal view (b) Right lateral view. N.B. The diagram of the thoracic vertebrae show in Figure 4.8 on page 94 of the text is not entirely accurate with respect to the shape and position of the transverse processes. Use this diagram.

READ

As youngsters we are often advised to "stand up straight." This means that our head should be erect, chest out, abdomen in and with the proper alignment of the ear, shoulder, hip, knee and ankle. Good posture does not mean that the vertebral column is perfectly straight but that its natural curves are not exaggerated.

Poor posture permits the head to tip forward, shoulders and chest to sag and the abdomen to protrude. Under these conditions, the thoracic curvature may become exaggerated producing a round-shouldered or hunchbacked condition known as **kyphosis**.

If the lumbar curvature becomes more exaggerated, **lordosis** or swayback may result. A lateral curvature of the spine is known as **scoliosis**.

Individual vertebrae are separated by cushions of fibrous cartilage known as ''discs.'' These discs act as shock absorbers. If they become displaced or ''slipped'' they may pinch some nerves in the spinal cord and cause acute pain.

Exercise 3

Indicate whether the following statements are True or False by circling the correct letter - (T) or (F).

T F 1. The atlas vertebra allows us to nod ''yes''.

T F 2. There are 5 cervical vertebrae in man.

T F 3. All of the 12 pairs of ribs join the thoracic vertebrae in the back and the sternum in the front.

T F 4. Most of the weight of the upper body is carried by the lumbar vertebrae.

T F 5. Muscles are attached to the processes of vertebrae.

T F 6. The sacral vertebrae are fused to the pelvic girdle.

T F 7. Man has a tailbone.

T F 8. The pain and damage of a ''slipped disc'' is usually from the vertebrae scraping together.

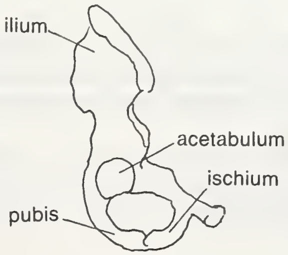
T F 9. ''Hunchback'' is a spinal disorder known as kyphosis.

T F 10. It is difficult for us to bend backwards because the spinal processes touch each other and prevent it.

Please check your work with the answers given on page 17.

The Appendicular Skeleton

A. The Pelvic Girdle and Its Appendages



Lateral View of Pelvis

The hipbones are the two large flat bones that form the pelvic girdle. These broad bones support body weight and are designed for childbearing in the female.

In the fetus, the pelvis develops from three separate bones; the **ilium**, the **ischium** and the **pubis**. If you ''put your hands on your hips'' then they would be on the **ilium**. We sit on the large projections or tuberosities of the **ischium**. The lower anterior portion of the pelvis are the **pubis bones**. The two pubic bones are joined by a disc of fibrocartilage which makes them slightly moveable. The pelvis is shorter and broader in the female than in the male, which is an asset for childbearing.

The leg consists of the long, heavy thigh bone (the **femur**) which forms a ball-and-socket joint with the pelvic girdle. At the distal end, the femur articulates with the tibia or "shinbone" to form a hinge joint at the knee. The knee is protected by the small flat **patella** (knee cap) which is embedded in muscle.

Lateral to the **tibia** is the **fibula**. Both tibia and fibula articulate with the 7 ankle bones or **tarsals** at the distal end. **Metatarsals** form the bones of the foot and the **phalanges** form the toes. The bones of the foot form natural arches. If the muscle tone is lost across these arches you may suffer painful aches in your feet from "fallen arches."

B. The Shoulder Girdle and Its Appendages

The shoulder girdle is composed of two **clavicles** or "collar bones" and two **scapulae** or "shoulder blades." These bones do not form a complete girdle since the **sternum** or "breastbone" separates them anteriorly and the scapulae are not attached to each other posteriorly. This incomplete shoulder girdle allows for the independent movement of each arm.

The head of the **humerus** (the bone of the arm above the elbow) fits into a circular depressed area in the scapula forming a ball-and-socket joint. The distal end of the humerus articulates with the **radius** and **ulna** (the bones of the forearm) forming a hinge joint at the elbow. The radius is able to pivot around the ulna allowing rotation of the arm.

Eight **carpals** make up the wrist. **Metacarpals** are the bones of the hand and 14 **phalanges** form the fingers - three for each finger and two for the thumb.

Exercise 4

Fill in the blanks.

1. The bone you sit on is the ______________. It articulates with the ______________ anteriorly and the large ______________ which forms the hip. The ______________ forms a ball-and-socket joint with the pelvic girdle at one end and the ______________ of the lower limb at the other. The other bone of the lower limb is the ______________. A flat bone embedded in the muscle over the knee is the ______________. The ankle is formed by ______________ and the foot by ______________.
2. The shoulder girdle consists of the ______________ and ______________. The bone of the upper arm, the ______________ fits into this girdle at one end and articulates with the ______________ and ______________ of the lower arm at the other. Eight ______________ make up the wrist and five ______________ make up the hand. Fingers and toes are made of ______________.

Please check your work with the answers given on page 18.

Joints

READ

Read the section in your textbook entitled "The Joints" (pp. 104 to 108).

An **articulation** is the junction between two bones or between bone and cartilage. Articulations or **joints** may permit no movement, slight movement or free movement. Joints are secured by **ligaments** which join bone to bone and by **tendons** which attach muscle to bone.

The freely moveable joints of the hip, elbow, knee and shoulder have a joint cavity with **synovial membranes** and **fluid**. You should become familiar with the following types of joints:

1. **ball-and-socket**
2. **hinge**
3. **gliding**
4. **pivotal**

Skeletal Injuries and Disease

READ

Read the section in your textbook on pages 108 to 110.

Bone is often broken by tension or torque forces. Fractures involve the soft tissue around the bones such as muscles, blood vessels, nerves, joints and skin as well as the bones themselves. Handling of fractures is critical, and sometimes more harm than good is done by people who are eager to help but are misinformed. Fractures may be **simple, compound** (breaks through the skin) or **incomplete** (greenstick fracture). Read about the steps in the repair of a broken bone in your textbook (pp. 109 and 110).

Bone is also sometimes affected by a bacterial disease in an infection known as **osteomyelitis**.

Disorders and injuries not only affect the bones of the skeletal system but also the joints. Some of the more common disorders of the joints include:

1. **Dislocations** - loss of continuity of joint structures.
2. **Sprains** - tearing of ligaments and muscles with pain and edema.
3. **Strains** - overstretching of ligaments and muscles with tearing.
4. **Arthritis** - inflammation in a joint.

The Muscular System

Read the section in your textbook entitled "The Muscular System" (pp. 115 to 118).

Muscle tissues are composed of specialized cells which are able to react to a stimulus, that is, they are **excitable**. When stimulated these tissues are able to become shorter and thicker (**contract**). Muscle cells may also become **extended** and then return to their normal length, thus displaying **elasticity**.

There are three types of muscle tissue found in the body, each having unique characteristics and all displaying the above general properties (see Figure 4).

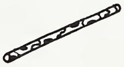
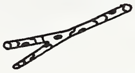
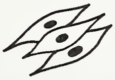
Muscle Type	Contraction Stimuli	Muscle Cell	Nuclei and Striations
Skeletal (body)	Voluntary	Long, cylindrical 	Many nuclei, strong striations
Cardiac (heart)	Involuntary	Short, branching fibers 	Oval nuclei, fine striations
Smooth (visceral)	Involuntary	Spindle-shaped 	Single nucleus, nonstriated

Figure 4: Muscle Types and Characteristics

Muscle Cell Contraction

Read the section in your textbook entitled "Muscle Contraction and Expansion" (pp. 118 to 120 and 125 to 126).

Skeletal muscle is found attached to the bones of the skeleton. It brings about movement of limbs and skeletal structures like the rib cage. Skeletal muscles tend to work in pairs (**antagonistic pairs**); the action of one muscle opposing the other. As the first contracts the second will relax.

The skeletal muscle tissue is made up of muscle fibres. Each muscle fibre was originally formed by repeated cell division of a single cell to produce a long continuous fibre with many nuclei and no apparent separations between the cells. Each fibre is composed of smaller units called **myofibrils**. In turn, each myofibril is composed of still smaller units called filaments. The characteristic striated appearance of skeletal muscles is the result of the way the filaments are arranged. Under chemical analysis, it has been found that filaments are composed of two different proteins - **myosin** (thicker filaments) and **actin** (thinner strands). Actin filaments are attached to cross bands called Z bands. The portion of the muscle fibre between two Z bands is called a **sarcomere**.

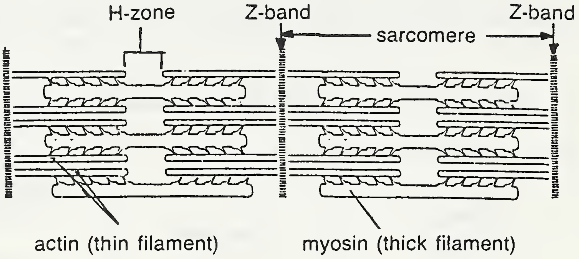


Figure 5: Structure of a Filament (sarcomere)

Upon stimulation from a nerve, these muscle proteins slide past one another. Cross-bridges between actin and myosin are formed; the actin filaments slide past each other and the muscle shortens (see Figure 6).

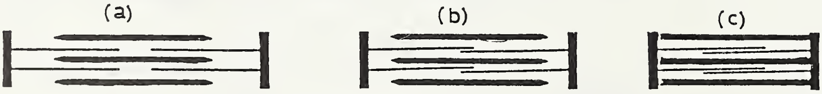


Figure 6: Schematic Representation of Muscle Contraction (a) Muscle fibril at rest (b) Muscle fibril contracting (c) Muscle fibril contracted.

Nerve impulses stimulate muscles to contract. The motor nerves have numerous extensions called **motor end plates** which release **acetylcholine** to cause membrane depolarization and eventual contraction. During the process of stimulation, calcium ions (Ca^{++}) are released. Calcium ions aid in the release of the energy from ATP. This energy is needed by the muscle.

After the muscle cells have been stimulated by acetylcholine, an enzyme (**acetylcholinesterase**) is released to break down the acetylcholine and clear the neuromuscular junction for the next impulse.

The Chemistry of Muscular Contraction

There are three sources of energy available for muscle contraction.

1. **ATP** stored in muscle fibres is the immediate source of energy. As you recall, ATP is produced by aerobic respiration. Its supply is limited and is used up quickly during muscular contraction.

2. The second source of energy is **creatine phosphate** (creatine $\sim\textcircled{P}$). Creatine phosphate is an important storehouse of energy-rich phosphate ($\sim\textcircled{P}$). When ATP is used up rapidly in muscular contraction, creatine $\sim\textcircled{P}$ will release $\sim\textcircled{P}$ which combines with ADP to be reconverted back to ATP. This reaction is illustrated in the formula below.

$$\text{creatine} \sim\textcircled{P} \quad + \quad \text{ADP} \xrightleftharpoons[\text{muscle relaxation}]{\text{muscle contraction}} \text{creatine} \quad + \quad \text{ATP}$$

Later, when the muscle fibres are at rest, the creatine is reconverted to creatine $\sim\textcircled{P}$ by picking up $\sim\textcircled{P}$ from ATP. Creatine $\sim\textcircled{P}$ is stored in muscle cells in high concentration for future use.

3. The third source of energy is **glycogen** which provides energy for prolongated muscle activity. As you recall from our studies in respiration, glycogen is converted to glucose which in turn is broken down to pyruvic acid. If there is sufficient amounts of O_2, aerobic respiration takes place and an abundant supply of ATP will be available. However, during intense prolonged exercise the circulatory system cannot keep up with the oxygen demand, and anaerobic respiration takes over. This process produces less ATP (2 compared to 36) and results in the production of **lactic acid**. The fatigue that aflicts muscles during energetic activity is due to the accumulation of lactic acid which is toxic to cells. Cramps are due to a lack of ATP which seems necessary for preventing rigid links from forming between actin and myosin. The rigidity of rigor mortis (death) is probably due to permanent links being made after cell respiration has ceased.

Deep breathing accompanies violent exercise and continues for some time after exercise is stopped. The reason for this is that oxygen is needed for aerobic respiration and to remove lactic acid which has accumulated.

Some of the lactic acid is converted to CO_2 and H_2O through the citric acid cycle. This results in the production of ATP. The bulk of the lactic acid is converted into glycogen to replenish the muscle's store. Energy left over from this task is "locked" in creatine-phosphate to prepare the muscle for more action. The deep breathing continues after exercise until the **oxygen** debt is paid i.e. enough oxygen has been supplied to convert lactic acid.

Exercise 5

Part One: Fill in the Blanks

1. All muscles are able to be ______________ by the nervous system and to ______________ . They may also be ______________________ beyond their normal length and display great ________________________ to return to normal.
2. Muscles under conscious or voluntary control which control running, walking and jumping are ______________ muscles. Heart muscles or _______________ muscles are under ___________________ control. The lining of the stomach, intestine and bladder are muscles called ______________ or visceral. They are under _____________________ control.

Part Two: Matching

Match the word or phrase in the right-hand column with the statement in the left-hand column.

_____ thick protein strands

_____ sheath continuous with tendons at the end of muscles

_____ striped appearance of skeletal muscle

_____ thin protein strands

_____ gap not seen when muscles contract

_____ divided into sarcomeres

_____ basic unit of muscle contraction

_____ energy source for prolonged muscle contraction

_____ part of motor nerve found at the neuromuscular junction

_____ chemical stimulating muscle contraction

A. sarcolemma
B. striations
C. myosin
D. actin
E. H band
F. Z line
G. myofibril
H. sarcomere
I. creatine phosphate
J. oxygen deficit (debt)
K. motor end plate
L. acetylcholine
M. glycogen
N. acetylcholinesterase

Please check your work with the answers given on page 18.

Characteristics of Muscular Contractions

A simple muscle contraction is called a **twitch**. Under experimental conditions, if a single shock (stimulus) is applied to the muscle then the following trace can be recorded (see figure 7):

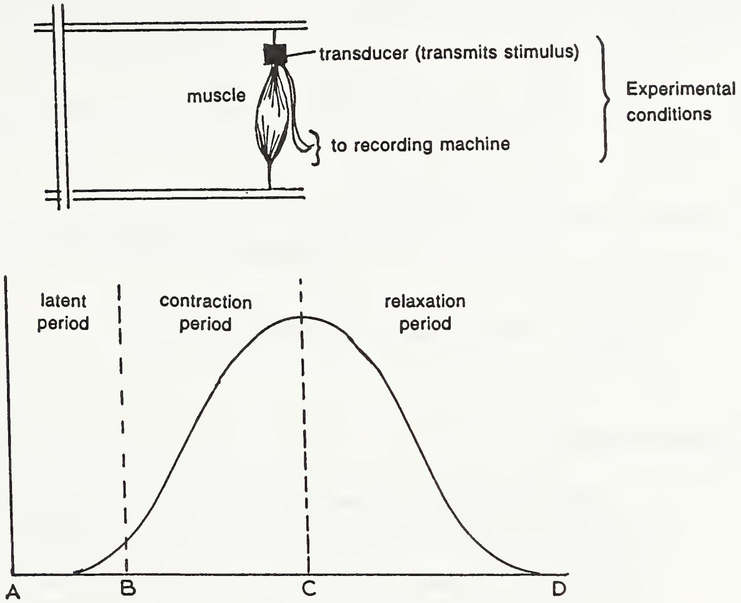


Figure 7: Muscle Contractions - A Muscle Twitch

The three phases of the twitch are the **latent period, contraction period,** and **relaxation period**.

1. **Latent Period** - 1/100 second - This is the time needed to conduct the impulse, release calcium ions and split ATP.
2. **Contraction Period** - time depends upon the type of muscle that is contracting. It may be 1/100 of a second in the eye (ocular) muscle, 1/25 of a second in the leg (gastrocnemius) muscle or 1/10 of a second in muscle that maintains our posture.
3. **Relaxation Period** - muscle fibres return to the relaxed position.

If the muscle is stimulated before it is allowed to relax, the muscle contraction will be greater than the first contraction. Continued stimulation of the muscle at an increased rate results in sustained contraction. Sustained muscle contraction without relaxation is known as tetanus. During tetanus, the muscle is continually under tension as the result of continual and rapid stimuli. Tetanus can continue until all of the actin and myosin fibrils have contracted to their fullest extent and the ATP is used up. Muscle fatigue then sets in (see figure 8).

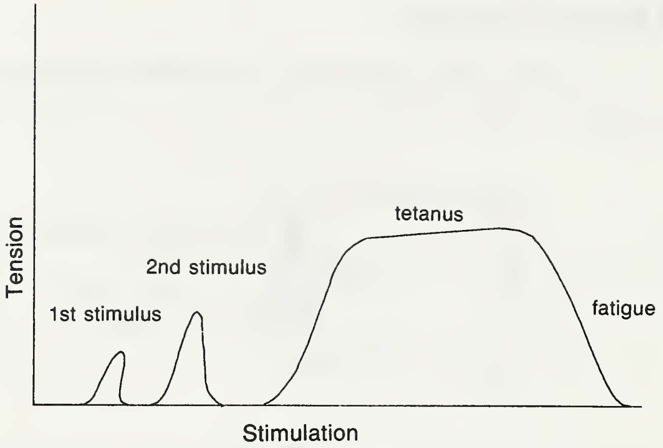


Figure 8: Muscle Under Continual Stimulation

Cardiac and Smooth Muscles

Cardiac muscle is a striated muscle where the myofibrils are aligned differently from the regular parallel rows in skeletal muscle. There are myofibrils forming crosslinks between one group of fibres and the next. Once a contraction starts it spreads throughout the entire portion of such a tissue. It is found in the heart where the entire musculature of the atria must contract, followed by the ventricles. Tetanus does not occur in cardiac muscle. This means that the muscle can keep contracting and the heart can continue beating throughout our lifetime.

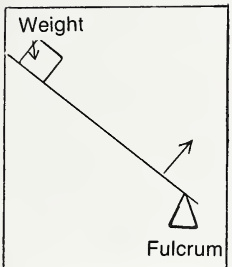
Smooth muscle is made up of individual nucleated cells which are long, slender and have pointed ends. Work with the electron microscope indicates contractile elements within the cell that are similar to the myofibrils found in a fibre of striated muscle. The smooth muscle is found in the walls of internal organs such as the gut and the walls of arteries and veins. Smooth muscle always maintains slight tension. Thus the muscular walls of the intestine exert a continuous force on their contents.

Muscles at Work

READ

Read the section in your textbook entitled ''Muscles in Action'' (pp. 121 to 128).

Muscles can move bones because they are attached to bone by bands of tough, elastic connective tissue called **tendons**. Tendons are protected by a tissue covering called the **tendon sheath**. These sheaths may contain fluid-filled sacs called ''bursae.'' These sacs are located over joints to protect the movements of tendons and prevent friction. There is a large bursa at the knee joint and others at the shoulder, elbow and hip. An inflammation of the bursae causes **bursitis** - an affliction more commonly known as ''tennis elbow'', ''housemaid's knee'', or ''subdeltoid bursitis'' (in quarterbacks and baseball pitchers).



3rd Class Lever

Muscles are usually attached at two points: the **origin** (fixed point) and the **insertion** (moveable point). In legs and arms, the origin is most often proximal (near the body midline) while the insertion is more distal (away from the body midline). The relationship of the force applied to the muscle, balance point (fulcrum) and resistance given by the muscles means that the muscles and bones act like a system of levers. For example, in a third class lever like the arm, force is sacrificed to obtain quickness of movement over a greater distance such as in throwing a baseball. Some baseball pitchers can throw a baseball 167 km/h (100 mi/h) even though their arm muscles shorten at only a fraction of this velocity.

A healthy muscle exhibits a constant slight contraction called **muscle tone**. Regular exercise and good posture improve the tone.

Be sure you can describe the various muscle actions of **flexion, extension, adduction, abduction** and **rotation.**

Muscular Disorders

READ

Read page 128 of your textbook.

ANSWERS TO SELF-CORRECTING EXERCISES

Exercise 1, p.3.

Match the following.

F	flexible, rubbery support tissue
H	ground substance containing calcium and phosphorus
I	little blood canals
A	porous light bone
D	soft bone centre producing red blood cells
C	tough membrane producing bone cells
G	bone cells
E	soft bone centre storing fat
K	cartilage plate allowing growth
J	blood vessel system supplying bone with nutrients

A. Spongy bone
B. Compact bone
C. periosteum
D. red bone marrow
E. yellow bone marrow
F. cartilage
G. osteocytes
H. matrix
I. canaliculi
J. Haversian canals
K. epiphysial plate

Exercise 2, pp. 4 and 5.

Part One: Fill in the Blanks

1. The axial skeleton consists of bones of the **head,** hyoid, **vertebral** column, sternum and **ribs**.
2. The moveable part of the skull is the **mandible**.
3. There are **8** cranial bones joined at immoveable joints called **sutures**. Spaces between bones of the developing child are called **fontanels**.
4. The **facial** bones protect the organs of sight, hearing and smell.

Part Two: Matching

Match the structure on the right with the description on the left

G	"cheek bones"
A	bone of the forehead
F	immoveable jaw bone

A. frontal
B. parietal
C. occipital

H	opening for inner ear
C	bone containing foramen magnum
D	bones on side of skull beside the ears
E	bones of bridge of nose
B	skull bones on top and side of head

D. temporal
E. nasal bones
F. maxilla
G. zygomatic bones
H. auditory meatus

Exercise 3, p.6.

True or False.

1. **True.**
2. **False.** There are 7 cervical vertebrae in man.
3. **False.** There are 2 pairs of floating ribs (unattached).
4. **True.**
5. **True.**
6. **True.**
7. **True.**
8. **False.** Pain from a "slipped disc" is due to a pinched nerve.
9. **True.**
10. **True.**

Exercise 4, p.7.

Fill in the blanks.

1. The bone you sit on is the **ischium**. It articulates with the **pubis** anteriorly and the large **ilium** which forms the hip. The **femur** forms a ball-and-socket joint with the pelvic girdle at one end and the **tibia** of the lower limb at the other. The other bone of the lower limb is the **fibula**. A flat bone embedded in the muscle over the knee is the **patella**. The ankle is formed by **tarsals** and the foot by **metatarsals**.

2. The shoulder girdle consists of the **clavicles** and **scapulae**. The bone of the upper arm, the **humerus** fits into this girdle at one end and articulates with the **radius** and **ulna** of the lower arm at the other. Eight **carpals** make up the wrist and 5 **metacarpals** make up the hand. Fingers and toes are made of **phalanges**.

Exercise 5, p. 12.

Part One: Fill in the blanks.

1. All muscles are able to be **excited** by the nervous system and to **contract**. They may also be **extended** beyond their normal length and display great **elasticity** to return to normal.

2. Muscles under conscious or voluntary control which control running, walking and jumping are **skeletal** muscles. Heart muscles or **cardiac** muscles are under **involuntary (autonomic)** control. The lining of the stomach, intestine and bladder are muscles called **smooth** or visceral. They are under **involuntary** control.

Part Two: Matching

C	thick protein strands
A	sheath continuous with tendons at the end of muscles
B	striped appearance of skeletal muscle
D	thin protein strands
E	gap not seen when muscles contract
G	divided into sarcomeres
H	basic unit of muscle contraction
M	energy source for prolonged muscle contraction
K	part of motor nerve found at the neuromuscular junction
L	chemical stimulating muscle contraction

A. sarcolemma
B. striations
C. myosin
D. actin
E. H band
F. Z line
G. myofibril
H. sarcomere
I. creatine phosphate
J. oxygen deficit (debt)
K. motor end plate
L. acetylcholine
M. glycogen
N. acetycholinesterase

EXERCISES TO BE SENT IN FOR CORRECTION

Exercise 1 - The Skeleton

1. List **five** important functions of the skeletal system.

(a) ______________________________

(b) ______________________________

(c) ______________________________

(d) ______________________________

(e) ______________________________

2. Give **two** reasons why the skull of a baby is composed of unfused plates.

(a) ______________________________

(b) ______________________________

3. For each of the following pairs of words give one **similarity** and one **difference**.

(a) Cartilage and Bone - ______________________________

____

____

____

(b) Compact Bone and Spongy Bone

____

____

____

4. State whether the following belong to the **axial** or **appendicular** skeleton.

(a) cervical vertebrae - ______________________

(b) humerus - ______________________

(c) clavicle - ______________________

(d) skull - ______________________

(e) temporal bone - ______________________

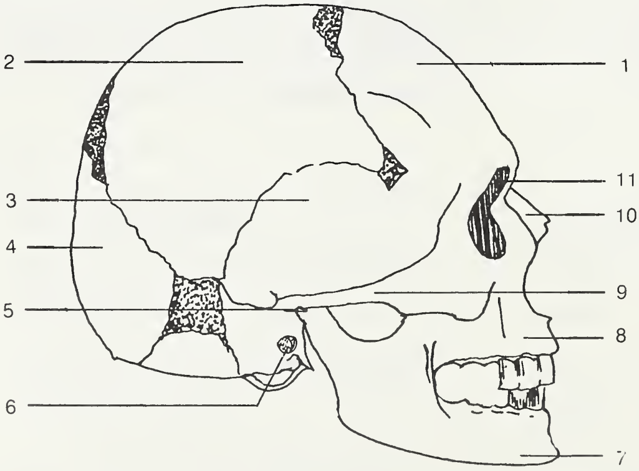
(f) mandible - ______________________

(g) radius - ______________________

(h) sacrum - ______________________

(i) atlas - ______________________

Using the following diagram answer the next 7 questions.



______ 5. The **parietal** bone:

(a) 1 (b) 2 (c) 3 (d) 4

______ 6. Structure through which sound waves reach the inner ear:

(a) 3 (b) 6 (c) 9 (d) 11

______ 7. Bone through which spinal cord enters the skull:

(a) 2 (b) 4 (c) 5 (d) 6

______ 8. The **zygomatic** bone:

(a) 3 (b) 5 (c) 9 (d) 10

______ 9. The **condyloid process**:

(a) 5 (b) 6 (c) 7 (d) 9

______ 10. Immoveable jaw bone:

(a) 5 (b) 7 (c) 8 (d) 9

______ 11. Bone containing the tiny bones of the ear:

(a) 3 (b) 4 (c) 5 (d) 6

Exercise 2

1. Which bones protect the following organs or structures?

(a) spinal cord - ______________________________

(b) heart and lungs - ______________________________

(c) knee - ______________________________

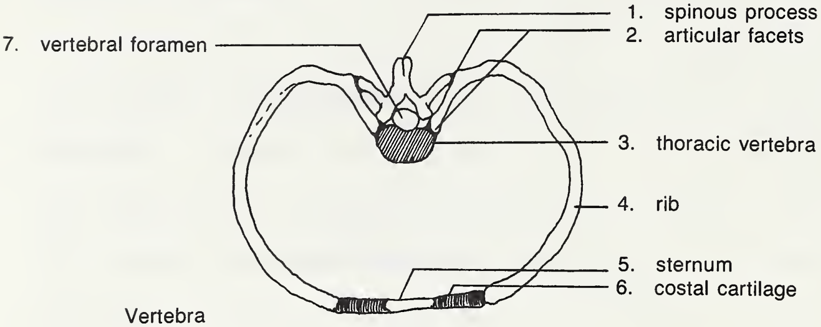
(d) brain - ______________________________

(e) inner ear - ______________________________

2. Is there any difference in the number of ribs between a male and female? ____________

There are ______________ pairs of ribs, ______________ pair of which are attached to the ______________, 3 pairs attached to each other by cartilage and ______________ pair of floating ribs.

Answer the following **three** questions using the following diagram:



Vertebra

______ 3. The structure you can feel if you run your finger down your spine:

(a) 1 (b) 2 (c) 3 (d) 5

______ 4. The structure through which the nerve cord passes:

(a) 1 (b) 3 (c) 6 (d) 7

______ 5. There are two pairs of these for rib attachment in thoracic vertebrae:

(a) 1 (b) 2 (c) 5 (d) 7

______ 6. The large-bodied vertebrae which support most of the upper body weight.

(a) cervical (b) thoracic (c) lumbar (d) sacral

______ 7. Vertebrae are fused in the ______ region(s).

(a) cervical and thoracic
(b) thoracic and lumbar
(c) lumbar and sacral
(d) sacral and coccyx

8. (a) What are the most outstanding features of cervical vertebra #1 (the atlas)?

(b) What are the most outstanding features of cervical vertebra #2 (the axis)?

Exercise 3

1. Briefly compare the male pelvis to the female pelvis.

2. What is the proper anatomical name for the following bones?

   (a) shoulder blade -
   (b) collar bone -
   (c) hip bone -
   (d) thigh bone -
   (e) the two bones of the forearm -
   (f) toes or fingers -
   (g) the two bones of the lower limb -
   (h) hand bones -
   (i) foot bones -
   (j) ankle bones -

3. Give one **similarity** and one **difference** between the following structures.

   (a) hinge joint and ball-and-socket joint

   similarity -

   difference -

   (b) gliding joint and pivot joint

   similarity -

   difference -

(c) tendon and ligament

similarity - ______________________________

____

difference - ______________________________

____

(d) dislocation and sprain

similarity - ______________________________

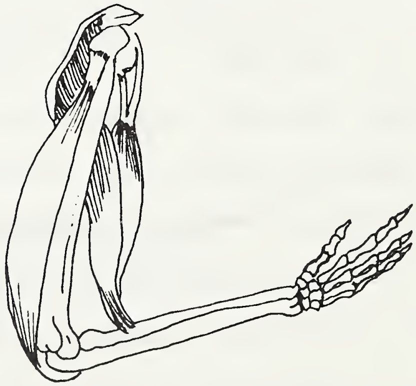
____

difference - ______________________________

____

Exercise 4 - Human Muscles

1. In the diagram below, **label the following structures:** joint, humerus, ulna, radius, flexor, extensor, origin and insertion.



2. In humans, one muscle group will oppose the directional movement of another muscle group. These two groups of muscles are referred to as ____________ pairs.

3. For the questions (a) to (f) use the following key. In the spaces below place the appropriate number from the key that best matches with the characteristics below.

(i) skeletal muscles
(ii) cardiac muscles
(iii) smooth muscles
(iv) skeletal and cardiac muscles
(v) cardiac and smooth muscles
(vi) all three muscles

______ (a) Striated appearance.

______ (b) Line the walls of the intestine and the blood vessels.

______ (c) Under voluntary control.

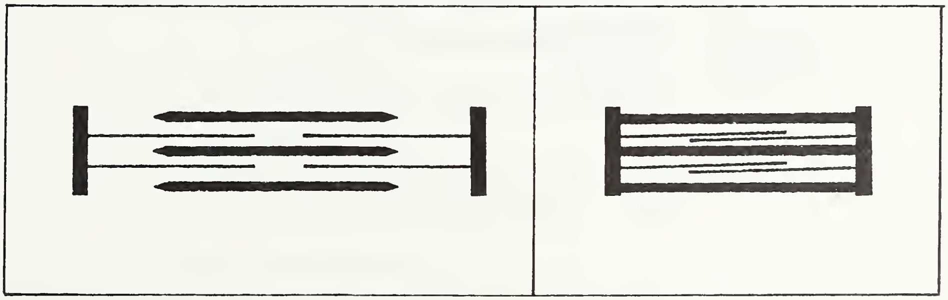
______ (d) Controlled by the autonomic nervous system.

______ (e) ATP provides energy for contraction.

______ (f) Contractions are self-initiated by the pacemaker.

Exercise 5 - How Muscles Work

1. The diagrams below illustrate relaxed and contracted states of myofibrils. In the blanks below indicate if the state is relaxed or contracted. Also **label the Z line, myosin and actin** in the diagrams.



______________________ ______________________

2. (a) The chemical messenger that depolarizes the skeletal muscle fibres at the end plate is ______________________.

(b) The chemical that destroys the above chemical is ______________________.

3. Briefly outline the chemical changes that occur in the muscle tissue of a runner from the time he starts to run through to the end of his run when he has completely recovered. Consider the following:'

(a) ATP production and use: -

(b) The role of creatine phosphate: -

(c) Oxygen debt: -

4. Distinguish between muscle tetanus and muscle tone.

Tetanus (not the disease) -

Tone -

Exercise 6 - Muscle Movement

1. True or False. Indicate if the following statements are True (T) or False (F).

T F (a) The insertion end of a muscle moves away from the muscle's origin when it contracts.

T F (b) Lifting weights is a good example of isotonic exercise.

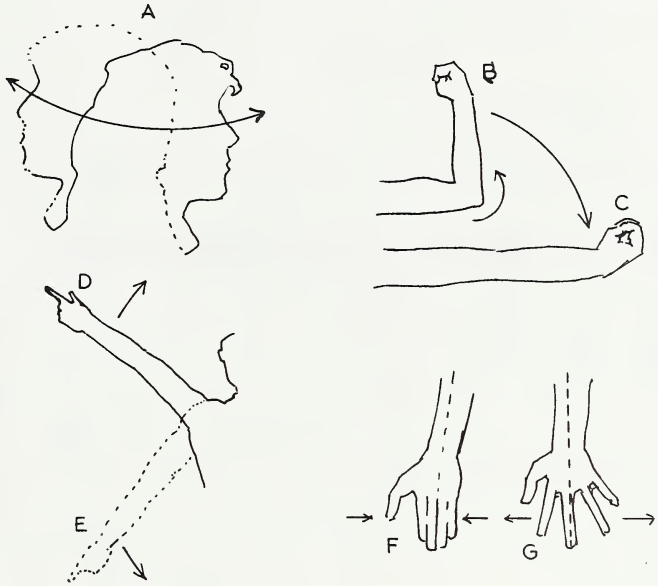
T F (c) "Housemaid's Knee" is caused by a torn ligament around the patella.

T F (d) Antagonistic pairs of muscles are required because muscles can "push" but cannot "pull."

T F (e) The biceps femoris and rectus femorus are an antagonistic pair of muscles.

2. Study the following diagrams of body movements and then indicate if they are examples of:

flexion
extension
adduction
abduction
rotation



(a) ________________

(b) ________________

(c) ________________

(d) ________________

(e) ________________

(f) ________________

(g) ________________

3. Explain briefly the meaning of the following terms:

   (a) Muscular dystrophy -

   (b) Muscle spasm -

Please submit pages 19 to 28 for correction.

END OF LESSON 7

LESSON RECORD FORM

3230 Biology 30

Revised 03/89

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Date Lesson Submitted ____________________

Time Spent on Lesson ____________________

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Lesson Number __________

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ALBERTA CORRESPONDENCE SCHOOL

MAILING INSTRUCTIONS FOR CORRESPONDENCE LESSONS

1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

First Class

Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

OBJECTIVES

When you have completed Lesson 8 you should be able to:

1. **List** the main structures through which air passes as it travels from the nose to the lungs.
2. **Discuss** how special structural features in the nose, pharynx, trachea, bronchi and alveoli aid the exchange of gases.
3. **Understand** where each of the three phases of external respiration take place.
4. **Illustrate** how the volume changes in the thoracic cavity are related to pressure changes.
5. **Show** the two major physical changes which take place during inspiration.
6. **Explain** expiration as a passive process.
7. **Understand** the terms related to lung capacity.
8. **Discuss** the concentration of oxygen and carbon dioxide in the lungs and in the tissues.
9. **Understand** the two major ways oxygen is transported in the blood.
10. **Understand** the three major ways carbon dioxide is transported in the blood.
11. **Discuss** why asphyxiation may occur rapidly with carbon monoxide.
12. **Locate** the major respiratory centre in the body.
13. **Explain** the effects of an increased carbon dioxide concentration and decreased oxygen content on the respiratory centre.
14. **Illustrate** how smoking may cause some respiratory diseases.
15. **Define** emphysema and lung cancer.

THE RESPIRATORY SYSTEM

Introduction

Our bodies can survive weeks without food, days without water but only minutes without oxygen. Oxygen must be obtained continuously from the environment as it cannot be stored in the body. Over 90 percent of the energy yield from organic nutrient compounds depends upon the presence of oxygen for the complete oxidation of glucose to carbon dioxide, water and energy (see Lesson 6). One of the basic problems of life then, is to procure oxygen and eliminate carbon dioxide.

Because we live on land and breathe dry air directly from our environment, man and other terrestrial vertebrates have developed lungs deep within our body to prevent the delicate respiratory structures from drying out. The lung system prevents the delicate tissues from drying out, but gas exchange becomes more complicated in the following ways:

1. Air must be flushed in and out of the system (breathing).
2. Gases must be transported to and from lungs and tissues.
3. The breathing rate must be controlled.

Please refer to the diagram below for an overview of the respiratory process.

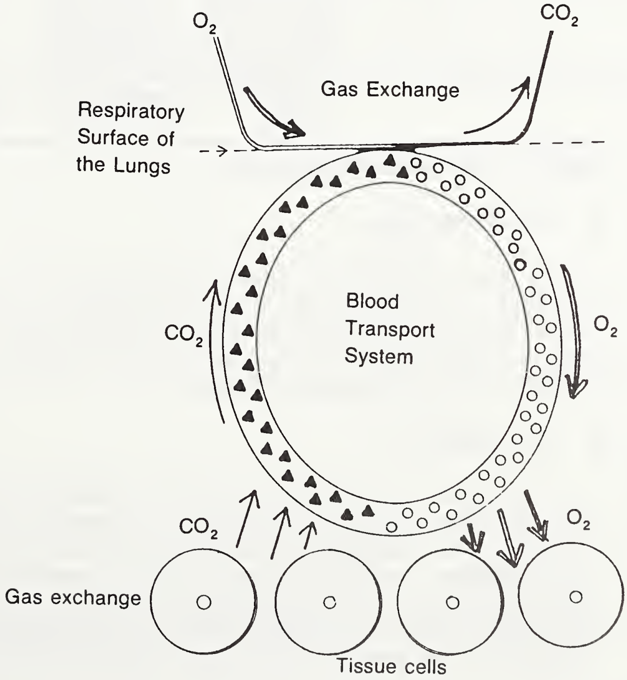


Figure 1: The Respiratory Process

Anatomy of the Respiratory System

READ

Read the section of your textbook entitled ''The Air-Conducting Structures.'' (pp. 275 - 280)

The anatomy of the respiratory system is shown in the diagram below and is well outlined in your textbook under the section entitled, ''The Air-Conducting Structures.''

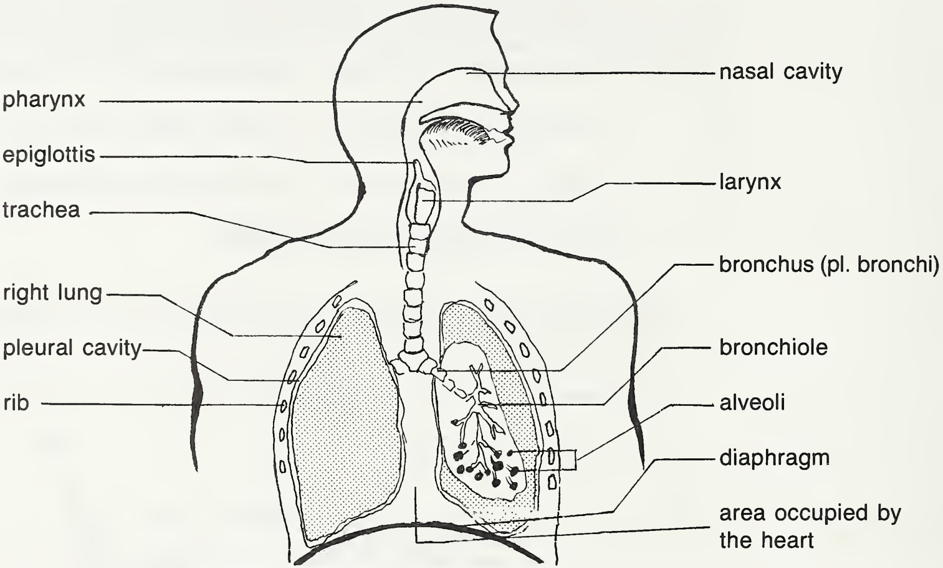


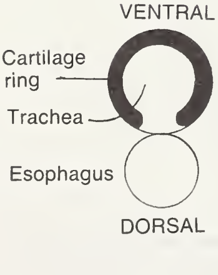
Figure 2: The Respiratory System

A. The Nasal Cavity

The nasal cavity is well supplied with blood vessels and covered with thin, ciliated membranes. As air moves over these membranes it is warmed and filtered. Particles are trapped by the mucous membranes and moved by small beating cilia toward the nasal passages. Cleaning the air is important since 20 billion particles of foreign matter may be breathed in by a city dweller each day.

B. The Trachea

Air passes down the back of the mouth or **pharynx** and into the **trachea** or windpipe. The 12 cm trachea connects the pharynx to the lungs. It is held open by ''C-shaped'' rings of cartilage. Run your fingers down the front of your neck and see if you can feel them. The **esophagus** of the digestive system is located behind the trachea. Food is moved down the esophagus to the stomach by a process known as peristalsis. The esophagus is able to move food by a series of muscular contractions (peristalsis) because it does not contain the cartilaginous rings present in the trachea. (see diagram in margin).



The upper end of the trachea is modified into the **voice box** called the **larynx.** It contains the "vocal cords" which help us make sounds when air is pushed through them from the lungs. The large cartilaginous plates forming the larynx can be felt at the front of the neck as the "Adam's apple."

If you have ever had food "go down the wrong way" you will appreciate the small flap of tissue called the **epiglottis** which guards the opening between the pharynx and the larynx. When food is being swallowed, the epiglottis closes, blocking entry to the trachea.

C. The Bronchi and Lungs

The trachea branches off into 2 tubes called the **bronchi**. Within the lungs the bronchi continue branching to form a large tree-like network of tubules known as the **bronchioles**. Each bronchiole ends in a cluster of microscopic sacs called **alveoli.** Air is able to diffuse easily across the single layer of epithelial cells and into the blood stream. Capillaries from the pulmonary artery carry deoxygenated blood to the alveoli while capillaries from the pulmonary vein carry oxygenated blood back to the heart.

Two thin membranous sacs called **pleura** surround the lungs as they lie within the thoracic cavity. Only a thin layer of film separates the inner **visceral pleura** from the outer **parietal pleura.** Their chief function is to reduce friction as the lungs move against the walls of the thoracic cavity. If the seal is broken between the two membranes, a collapsed lung may result. Some diseases such as pneumonia, tuberculosis and influenza may result in inflammation of the pleura, known as **pleurisy.** Two of the symptoms of pleurisy are fever and difficult, shallow breathing.

Exercise 1

1. List, in order, the structures through which air passes as it moves from the nose into lungs.

nose
↓
____
↓
____
↓
____
↓
____
↓
____

2. What evidence can you see, when breathing on a cold day, that air is warmed by the respiratory system?

____

3. Cartilage stiffens the trachea and larger bronchi to prevent their ____________ during ______________. Tracheal rings are "C-shaped" so that the ______________ lying behind it may expand as ____________ passes down it. The ____________ prevents food from entering the trachea.

4. The surface area of the lungs is greatly increased by the presence of clusters of ______________. These are made of a single layer of ____________ and are well supplied with blood ____________ to facilitate diffusion of ____________.

5. Pleurisy is caused by an inflammation of the ______________ that surround the lungs. Separating these two may result in a collapsed lung.

Please check your work with the answers given on page 10.

The Mechanics of Breathing

READ

Please read the section in your textbook entitled "The Mechanism of Breathing" (pp. 281 - 283).

The lungs themselves do **not** contain any muscle as this would interfere with the rapid exchange of gases. Therefore movement of gases into and out of the lungs depends upon **differences in pressure.** Recall that substances move from an area of high pressure to an area of lower pressure. When the pressure in the thoracic cavity is less than that of the surroundings, air will move into the lungs. Air is forced out of the lungs when the thoracic cavity is under greater pressure than the surrounding air. Changes in pressure are accomplished by **changes in volume** of the thoracic cavity. The greater the volume, the lower the pressure.

A. Inspiration

During quiet inspiration, the volume of the thoracic cavity is increased by pulling the **diaphragm** downward and flattening it out. The volume of the chest cavity is also increased by moving the whole rib cage upward and outward. The rib cage moves by the contraction of the **intercostal muscles** which lie between the ribs. Air moves into the area of reduced pressure through the nose and trachea into the lungs.

B. Expiration

Quiet expiration is **passive,** requiring no muscle movement. Muscles of the diaphragm and intercostals relax and air moves from an area of higher to lower pressure, i.e. the air leaves the lungs.

Deep inspiration and expiration, such as during exercise, call upon other muscles (eg. neck, sternum and stomach muscles) to further increase or decrease the lung capacity and create a greater difference in the pressures involved.

C. Lung Capacity

Let us review the terms used to describe lung capacity.

1. **Tidal Volume** - standard air flow into and out of lungs.
2. **Vital Capacity** - volume following maximal inspiration and expiration.
3. **Inspiratory Reserve Volume** - maximum amount of air inspired on quiet inspiration.
4. **Expiratory Reserve Volume** - maximum amount of air expired on quiet expiration.
5. **Residual Volume** - amount of air remaining after exhaling.
6. **Total Lung Capacity** - sum of residual volume + vital lung capacity.

Exercise 2

Part One: True or False

Indicate whether the following statements are True or False by circling the correct letter - (T) or (F).

1. Inspiration occurs when muscles in the lungs increase the volume of the lungs. T F
2. Expiration is normally a passive process. T F
3. There is a direct relationship between an increase in the volume of the thoracic cavity and a decrease in air pressure. T F
4. The diaphragm becomes stretched and flat and the intercostal muscles contract during inspiration. T F
5. The diaphragm becomes bowl shaped and the intercostal muscles relax during expiration. T F

Part Two: Fill in the Blanks

Tidal volume is about _______ cm^3 and represents the amount of air moved while a person is at _________. Vital capacity is the sum of _________ volume, __________ reserve volume and ____________ reserve volume. The vital capacity is about __________ cm^3. Total lung capacity is about __________ cm^3.

Please check your work with the answers given on pages 10 and 11.

READ

Please read the section of your textbook entitled, "The Exchange of Gases." (pp. 283 to 286)

Gas Exchange

The breathing mechanism you have studied so far has moved gases between the environment and the alveoli. The rest of the process of respiration involves the exchange of gases, first between alveoli and the blood, and then between blood and tissues.

Oxygen, in high concentration in the alveoli following inspiration, diffuses through the thin film of moisture which surrounds the alveoli and enters the blood stream. The watery part of the blood or **blood plasma** does not have the capacity to carry all the oxygen that is needed by the tissue cells. Most oxygen is transported by the respiratory pigment called **hemoglobin** found in the **red blood cells.**

Blood rich in oxygen leaves the lungs and enters the left side of the heart. The pumping action of the heart forces the blood through a network of arteries, arterioles and capillaries on its way to the tissues. Here the blood delivers oxygen to the cells and in turn removes carbon dioxide, which is the waste gas produced during cellular respiration. The blood returns to the right side of the heart where it is pumped back to the lungs to begin the cycle again.

Transport of Gases

A. Oxygen

Most oxygen is carried by hemoglobin molecules in the red blood cells. Hemoglobin combines with oxygen to form oxyhemoglobin (HbO_2). In the tissues this reaction is reversed, resulting in the separation of oxygen and hemoglobin.

$$\underset{\text{hemoglobin}}{\mathrm{Hb}} + \underset{\text{oxygen}}{\mathrm{O_2}} \; \underset{\text{tissues}}{\overset{\text{lungs}}{\rightleftharpoons}} \; \underset{\text{oxyhemoglobin}}{\mathrm{HbO_2}}$$

B. Carbon dioxide

Carbon dioxide is transported by the blood in three ways:

1. as a molecule dissolved in blood plasma (10%).
2. as a molecule of hemoglobin (25%).
3. as part of the bicarbonate ion (65%).

The concentration of carbon dioxide is high in the tissues and may become loosely combined with hemoglobin to form **carbaminohemoglobin ($HbCO_2$).** In the lungs the carbon dioxide concentration is low and the reaction is reversed, resulting in the separation of the carbon dioxide and hemoglobin. The hemoglobin released may then pick up either oxygen or carbon dioxide.

$$\underset{\text{hemoglobin}}{Hb} + \underset{\text{carbon dioxide}}{CO_2} \underset{\text{lungs}}{\overset{\text{tissues}}{\rightleftharpoons}} \underset{\text{carbaminohemoglobin}}{HbCO_2}$$

Most carbon dioxide (about 65%) is carried in the form of a bicarbonate ion. Initially carbon dioxide dissolves in the water portion of the blood to form a weak acid, **carbonic acid.**

$$\underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} \underset{\text{lungs}}{\overset{\text{tissues}}{\rightleftharpoons}} \underset{\text{carbonic acid}}{H_2CO_3}$$

Carbonic acid usually dissociates quickly to form **hydrogen** and **bicarbonate ions.**

$$\underset{\text{carbonic acid}}{H_2CO_3} \rightleftharpoons \underset{\text{hydrogen ions}}{H^+} + \underset{\text{bicarbonate ions}}{HCO_3^-}$$

Exercise 3

Indicate whether the following statements are True or False by circling the correct letter - (T) or (F).

1. Gases in the respiratory system always move from an area of high concentration to an area of low concentration. T F

2. Oxygen concentration is highest in the tissues. T F

3. Carbon dioxide is released from hemoglobin in lung capillaries because the surrounding tissues have low concentrations of carbon dioxide. T F

4. Blood travelling to the left side of the heart is high in oxygen. T F

5. Blood leaving the right side of the heart is also high in oxygen. T F

6. Gases diffuse across the alveoli in a thin film of cellular fluid. T F

7. Hemoglobin carries only oxygen. T F

8. Carbon dioxide and oxygen may dissolve directly in blood plasma. T F

9. An acid is formed when carbon dioxide and water combine. T F

10. Carbon monoxide is more closely bound to hemoglobin than carbon dioxide. T F

Please check your work with the answers given on page 11.

Nervous Control of Breathing

READ

Please read the section in your textbook entitled, ''Control of the Amount of Oxygen Delivered.'' (pp. 286 to 287)

The normal rhythm of breathing continues, even in our sleep, without a conscience effort on our part. There are **respiratory centres** located in the **medulla** of our brain. Stimulation of the inspiratory centre leads to inspiration while stimulation of the expiratory centre leads to expiration. These centres respond to a variety of stimuli.

During rigorous exercise we produce an excess of carbon dioxide and use more oxygen. This combination produces an increased rate of respiration. The most **direct stimulus** on the respiratory centre is the **increase** of **carbon dioxide**.

An infant takes its first breath shortly **after** birth because there is no need for breathing in the uterus. While in the uterus the fetus obtains oxygen from the mother. We usually think of a ''spank'' as the stimulus for the first breath but it could also be a change in temperature or the build up of carbon dioxide which initiates breathing.

Smoking

Please read the section in your textbook entitled "Smoking." (pp. 290 to 291)

Smoking can adversely affect the respiratory system and may result in debilitating conditions such as lung cancer or emphysema. Tobacco smoke contains many agents that may be harmful to our lungs. Smoking causes substances to be deposited on the bronchi. Some of these substances inhibit the action of the cilia while other substances can often cause cancer.

Tobacco smoke contains known **carcinogens** or agents known to cause cancer. The rapid increase of abnormally formed cells will obstruct the functioning of healthy lung cells.

Emphysema is also intimately related to cigarette smoking. In this disease, the walls of the alveoli are broken down and fewer but larger alveoli are formed. This results in a reduction of total area available for the diffusion of gases.

Exercise 4

Fill in the blanks.

1. The ______________ of the brain controls breathing. Here the ________________ centre is found. Centres are found within it for both ________________ and ________________. The most direct stimulus to this area is an excess of __________ __________.

2. Tobacco ______________ contains many compounds which may affect the health of your ____________. Cancer-causing agents or ________________ may stimulate the growth of abnormal __________.

3. ____________________ is a disease where the total surface area available for the ____________ of gases is ________________. The alveoli become broken and ____________ in number.

Please check your work with the answers given on page 11.

ANSWERS TO THE KEYED EXERCISES

Exercise 1, pp. 3 and 4.

1. nose
↓
pharynx
↓
trachea
↓
bronchi
↓
bronchiole
↓
alveoli

2. a cloud of water droplets condensing in the air.

3. Cartilage stiffens the trachea and larger bronchi to prevent their **collapse** during **breathing**. Tracheal rings are "C-shaped" so that the **esophagus** lying behind it may expand as **food** passes down it. The **epiglottis** prevents food from entering the trachea.

4. The surface area of the lungs is greating increased by the presence of clusters of **alveoli**. These are made of a single layer of **cells** and are well supplied with blood **capillaries** to facilitate diffusion of **gases**.

5. Pleurisy is caused by an inflammation of the **membranes (pleura)** that surround the lungs. Separating these two may result in a collapsed lung.

Exercise 2, pp. 5 and 6.

Part One: True or False

1. **False** The lungs themselves do not contain any muscle. Inspiration is achieved by pulling the diaphragm downward and by moving the whole rib cage upward and outward.
2. **True**
3. **True**
4. **True**
5. **True**

Part Two: Fill in the Blanks

Tidal volume is about **500** cm^3 and represents the amount of air moved while a person is at **rest**. Vital capacity is the sum of **tidal** volume, **inspiratory** reserve volume and **expiratory** reserve volume. The vital capacity is about **4000** cm^3. Total lung capacity is about **5500** cm^3.

Exercise 3, pp. 7 and 8.

True or False Questions

1. **True**
2. **False.** The highest concentration of oxygen is found in the alveoli following inspiration.
3. **True**
4. **True**
5. **False** Blood leaving the right side of the heart has a low concentration of oxygen. This blood has just returned from supplying the body with oxygen.
6. **True**
7. **False** Hemoglobin also carries carbon dioxide from the tissues to the lungs.
8. **True**
9. **True**
10. **True**

Exercise 4, p. 9.

Fill in the blanks.

1. The **medulla** of the brain controls breathing. Here the **respiratory** centre is found. Centres are found within it for both **inspiration** and **expiration**. The most direct stimulus to this area is an excess of **carbon dioxide.**

2. Tobacco **smoke** contains many compounds which may affect the health of your **lungs**. Cancer-causing agents or **carcinogens** may stimulate the growth of abnormal **cells**.

3. **Emphysema** is a disease where the total surface area available for the **diffusion** of gases is **decreased**. The alveoli become broken and **fewer** in number.

EXERCISES TO BE SENT IN FOR CORRECTION

Exercise 1 - Anatomy

Part One: Multiple Choice

For each of the following questions, choose the best answer and write the appropriate letter in the blank provided.

_______ 1. The smallest tube-like structure in the respiratory system is the

(a) bronchiole.
(b) trachea.
(c) bronchus.
(d) alveolus.

_______ 2. The structure responsible for the production of sound when we speak is the

(a) pharynx.
(b) larynx.
(c) esophagus.
(d) epiglottis.

_______ 3. The layer of muscle that separates the thoracic from the abdominal cavity is called the

(a) external intercostals.
(b) rectus abdominis.
(c) internal intercostals.
(d) diaphragm.

_______ 4. Food is prevented from entering the trachea due to the presence of the

(a) turbinate bones.
(b) Eustachian tube.
(c) epiglottis.
(d) larynx.

_______ 5. Breathing through your mouth is not as good as breathing through your nose because the air is **not**:

(a) warmed.
(b) cleaned.
(c) passed through the trachea.
(d) (a) and (b)
(e) all of the above

Part Two: Short Answer

1. What is the function of the pleural membranes?

2. What is the advantage of the cartilage rings seen in the trachea and large bronchi?

3. How are sounds made in the larynx?

Exercise 2 - Breathing

Short Answer

1. List **two** actions which result in an increase in volume of the thoracic cavity for inspiration.

   (a) ____________________

   (b) ____________________

2. Briefly explain how the rib cage and diaphragm cause expiration.

3. (a) What is meant by the vital capacity of a person?

   (b) Can the vital lung capacity be increased or decreased?

4. The amount of air flowing in and out of the lungs during quiet breathing is called the

   ____________________.

5. After all the expiratory reserve volume has been emptied out, are the lungs empty of air? Explain your answer.

____

____

Exercise 3 - Transport and Exchange of Gases

1. List the three places in the body where gases are exchanged in the respiratory system.

(a) ______________________________

(b) ______________________________

(c) ______________________________

2. The reactions involving hemoglobin and oxygen, and hemoglobin and carbon dioxide are reversible reactions. Next to the equations below indicate where each would take place (ie. lungs or tissues).

(a) $Hb + CO_2 \longrightarrow HbCO_2$ ______________________________

(b) $HbO_2 \longrightarrow Hb + O_2$ ______________________________

(c) $HbCO_2 \longrightarrow Hb + CO_2$ ______________________________

(d) $Hb + O_2 \longrightarrow HbO_2$ ______________________________

3. Why does asphyxiation with carbon monoxide occur so rapidly?

____

____

4. At the level of the tissue cell, the gas in highest concentration in the blood stream is ____________. Inside the cells themselves ____________ is in highest concentration and leaves to enter the blood stream where it is in ____________ concentration.

Exercise 4 - Control of Breathing

1. What part of the brain controls breathing?

2. Why does a person's rate of breathing increase after running?

3. Why can a person hold their breath for only a relatively short period of time?

Exercise 5 - Smoking

1. Discuss two diseases a heavy smoker may experience as a result of this habit.

Please submit pages 12 to 15 for correction.

END OF LESSON 8

LESSON RECORD FORM

3230 Biology 30

Revised 03/89

FOR STUDENT USE ONLY

Date Lesson Submitted ____________________

Time Spent on Lesson ____________________

(If label is missing
or incorrect)

File Number ____________________

Lesson Number __________

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Assigned Teacher: __________

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Additional Grading E/R/P Code: __________

Mark: __________

Graded by: __________

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ALBERTA CORRESPONDENCE SCHOOL

MAILING INSTRUCTIONS FOR CORRESPONDENCE LESSONS

1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

2. POSTAGE REGULATIONS

Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

First Class

Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.

OBJECTIVES

If you conscientiously complete the prescribed work contained in this lesson you will be capable of carrying out the following correctly.

1. **Define** cardiac output and explain how it is calculated.
2. **Compare** the effects of the sympathetic and parasympathetic nerves of the autonomic nervous system on heart rate.
3. **Identify** the position of the heart in the body.
4. **Identify** the chambers, blood vessels leading to and away from the heart and all the heart valves.
5. **Describe** the initiation and conduction of impulses by way of the electrical conduction system of the heart.
6. **Discuss** or trace the route of blood into and out of the heart.
7. **Discuss** the cardiac cycle utilizing the terms systole and diastole.
8. **Explain** or illustrate what is meant by cardiac output.
9. **Understand** the principal differences between the closed and open circulatory systems.
10. **Identify** the vital functions of the circulatory system.
11. **Compare** the manner in which blood is distributed under pressure in the arteries and the manner in which blood is returned to the heart via the veins.
12. **Be conversant** with the relationship between structure and function as regards the three types of blood vessels.
13. **Explain** how blood is returned to the heart from the lower extremities of the body.
14. **Identify** the divisions of the circulatory system.
15. **Discuss** the cardiac cycle, and the conduction system of the heart.
16. Be better able to **understand** the production and diagnostic value of heart beat sounds, blood pressure and the pulse.

THE HEART AND CIRCULATION OF THE BLOOD

Introduction

Living organisms require oxygen, water and food for survival. These substances must have a means of getting to the cell or cells. Furthermore, useful substances produced in the cells and also the waste products must leave the cell or cells and be transported away from them. When substances are transported into cells, the process is usually called **absorption**; when substances are transported to and from cells in the body the process is called **circulation**.

Microorganisms and very tiny animals have no need for a special transport system. For such tiny animals the processes of diffusion, active transport and cytoplasmic streaming are sufficient to ensure that every section of the cell or body is well supplied with all the necessary materials. The amoeba and small marine organisms are among small organisms which need no special circulatory system.

In multicellular organisms, however, the various structures that transport materials to different parts of the body makes up what is called the **circulatory system**. In animals there are two types of circulatory systems. One type is called an **open circulatory system**. The other kind of circulatory system is called a **closed circulatory system**.

The Open Circulatory System

In the open circulatory system, the circulatory fluid, normally called blood, is pumped a short distance from the heart in vessels and then enters the spaces between cells. The fluid bathes cells directly, exchanging materials with them by diffusion, before returning to the heart.

In this type of circulatory system although the blood is partly contained in the heart and vessels, these structures are not connected to form a complete circuit. In the body of insects for example, blood is pumped by the contraction of a tubular heart and a short aorta attached to its forward end. The end of the aorta is open. Blood from the heart flows into the aorta and then into body spaces called **sinuses**. From the sinuses, blood returns to the heart and when the heart relaxes, the returning blood enters it by way of several openings in its walls. As soon as the heart contracts again, blood enters the aorta and the process is repeated.

Please note that in the **open circulatory system**, the cells are **bathed directly** by the blood, a situation which differs from that in the closed system. Actually in the closed circulatory system, blood is always enclosed in vessels and under normal conditions does not enter the body cavity.

The Closed Circulatory System

The closed circulatory system retains blood within arteries, veins and capillaries. Under normal conditions blood never gets into the abdominal cavity. Consequently, the actual body cells are separated from the blood not only by the walls of the blood vessels but also by a space between the vessels and the cells. The spaces around the cells are filled with a fluid, **lymph** (extracellular fluid). The exchange of materials between the blood and the cells occurs through this fluid.

Blood pressure within the circulatory system drives the contents of the blood (except blood cells and most proteins) through the walls of small vessels called **capillaries** into the lymph. The processes of diffusion and active transport enable the cells to obtain from the lymph such substances as glucose, amino acids and oxygen. Waste products from the cells such as carbon dioxide, ammonia and a variety of salts are deposited in the lymph and from there enter the capillaries to become part of the venous blood. The waste materials are eliminated from the body by the skin (sweat), the kidneys (urine) and the lungs (air/vapour).

In a closed circulatory system the blood pressure is usually high and the rate of flow rapid. This is due to the pumping action of the heart.

READ

Read the sections of your text dealing with the heart and circulatory system (pp. 227 - 244).

THE HUMAN HEART AND CIRCULATORY SYSTEM

The heart is the center of the circulatory system. Along with the rest of the circulatory system the heart carries out the vital role of maintaining the circulation of blood throughout the body. The primary function of the circulating blood is **transportation**. The circulatory system is a system of closed tubes and a pump that transports essential elements throughout the body and in the process, collects cellular waste materials produced by cellular activity.

Functionally the circulatory system provides the tissues with a continuous flow of blood that bathes them and provides them with a slight alkalinity; it supplies the tissues with food and oxygen; it transports the building materials for their growth and repair; it distributes heat throughout the body as it is generated by the cells thus maintaining a constant body temperature; it distributes hormones produced by specific glands and utilized by the body to stimulate and co-ordinate the activities of body organs; it transports and distributes medication administered for therapeutic uses and distributes cells and antibodies for the body's defences.

The Heart

This four-chambered muscular organ about the size of a large fist, is located in the thoracic cavity. It is well protected by the rib cage. It lies in the middle section of the thorax, between the lungs. The apex of the heart rests on the diaphragm and points toward the left side.

Surrounded by a special membraneous sac which is loose fitting - the **pericardium** , the heart is not rigidly attached to any surrounding tissue but is able to move loosely in place as it contracts. The pericardium protects the heart from friction caused by contact with other parts of the body and also acts as a supporting structure. The pericardium is both flexible and elastic, stretching and shrinking as the heart fills with blood and then empties.

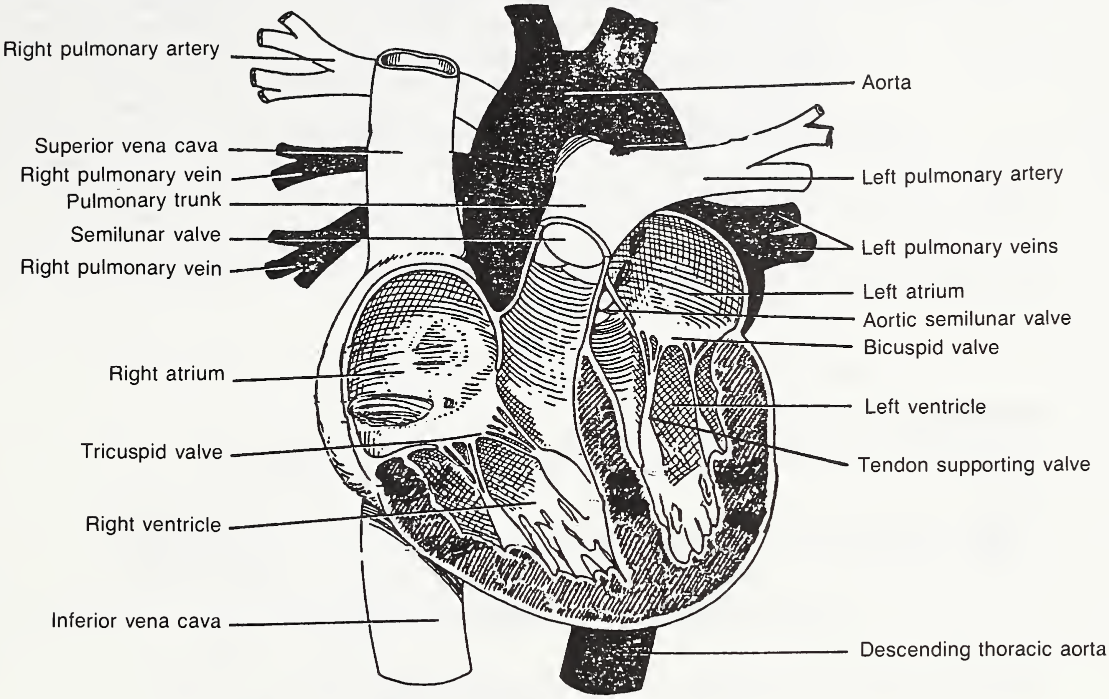


Figure 1: Diagram of the Heart - Longitudinal Section

Heart Muscle

The heart is composed of a very special muscle tissue. Like any muscle, heart muscle can be stimulated. In many ways heart muscle behaves like skeletal muscle but there are some exceptions. Skeletal muscles will contract only if they receive some kind of external stimulus. Normally the stimulus is a nerve impulse leading to the muscle. This is not the case with heart muscle which has the capacity to excite itself.

To demonstrate this excitability one could remove the heart from a coldblooded animal such as a frog, place the heart in a dish and cover it with Frog Ringers solution. The heart continues to beat, although completely disconnected from the body. Experiments have shown that when researchers went further and cut the heart into pieces, the pieces continue to beat. The pieces beat at various rates, that is, the pieces from the atria (upper part) beat faster than those from the ventricles. Scientists are not able to say precisely what causes the built-in rhythm of the heart. When the heart is intact there is only one rhythm due to an excellent conduction system which spreads the excitement of one section of the heart throughout the entire organ. Cardiac muscle cells are not attached to bones or other tissues.

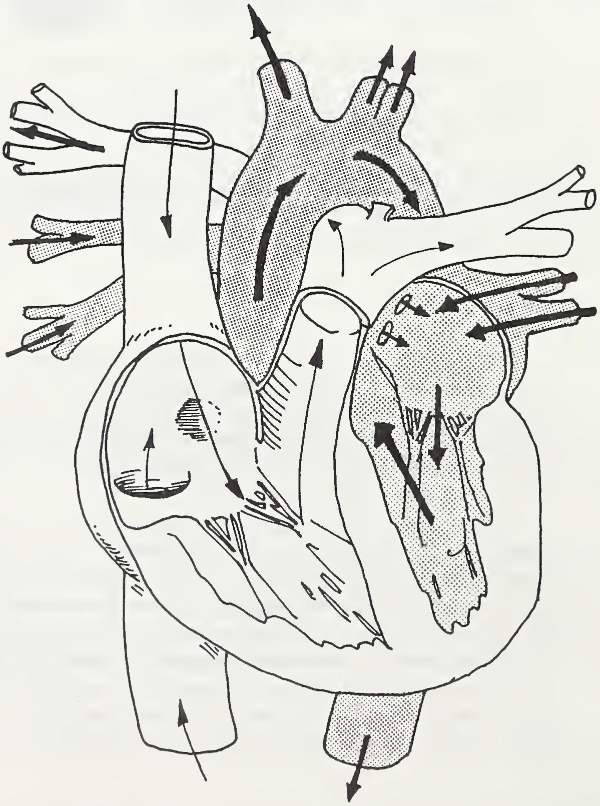
The Parts of the Heart

The human heart may be described as a double pump that operates continuously as long as a person lives. This remarkable organ which acts as a pump shows a unique design. The right and left halves though functioning in unison perform different functions. Furthermore the right and left halves (the two pumps) are welded together by a thick dividing wall, the **septum**. In addition to being divided into right and left halves, each side of the heart is again subdivided into **two chambers** - the upper chamber being the **atrium** and the lower chamber the **ventricle**. The **atria** (singular atrium) **receive** blood. When they contract they pump the blood into the lower chambers, and then relax for a short interval. The **ventricles,** the lower chambers, have thick walls. As the ventricles contract they pump blood out of the heart and relax for a brief interval. The thickness of the walls of ventricles and atria vary due to the function of each type of chamber. The atria squeeze blood into the ventricles, which is a short distance. The ventricles on the other hand pump blood to the lungs and the extremities of the body.

Exercise 1

1. Label the given terms on the diagram that follows:

aorta
pulmonary veins
left atrium
bicuspid valve
left ventricle
right ventricle
semilunar valves
pulmonary arteries
right atrium
tricuspid valve
left ventricle



2. Circle your choice TRUE or FALSE.

T F (a) Every body cell requires water, oxygen and food in order to survive.

T F (b) All living animals possess a circulatory system.

T F (c) The function of a circulatory system is transportation.

T F (d) Some animals have both a closed and an open circulatory system.

T F (e) In organisms with an open circulatory system, the cells are bathed directly by the blood.

T F (f) Lymph is a fluid that fills the spaces around cells.

T F (g) In organisms with an open circulatory system blood pressure is usually high and blood flow very rapid.

T F (h) The primary function of the circulating blood is transportation.

T F (i) Heart muscle cannot be stimulated to contract.

T F (j) Pieces cut from various parts of the heart of a cold-blooded animal contract at varying rates.

T F (k) Cardiac muscles are attached to bones and other tissues just like any other muscle.

T F (l) The thickness of the atrial and ventricular walls is the same throughout the heart.

T F (m) The atria, being the lower chambers of the heart, receives blood returning from the lungs and systemic circulatory system.

T F (n) When substances are transported into cells the process is absorption.

Please check your answers with those given on page 23.

Heart Valves

As each chamber of the heart contracts, it pushes a portion of blood either into a ventricle or out of the heart through an artery. But as the walls of these same chambers relax, blood must be prevented from flowing back into the structure. Heart valves prevent backflow of blood into the chambers.

The heart valve located in the passageway between the right atrium and the right ventricle is called the **tricuspid valve**. The tricuspid valve prevents backflow of blood into the atrium after the right ventricle contracts. On the other hand the valve located in the passageway between the left atrium and the left ventricle is called the **bicuspid** or **mitral valve**. It prevents backflow of blood into the atrium after the left ventricle contracts.

The valves we have just discussed are called the **atrioventricular valves** or (A-V valves) because they are located between the atria (plural of atrium) and the ventricles.

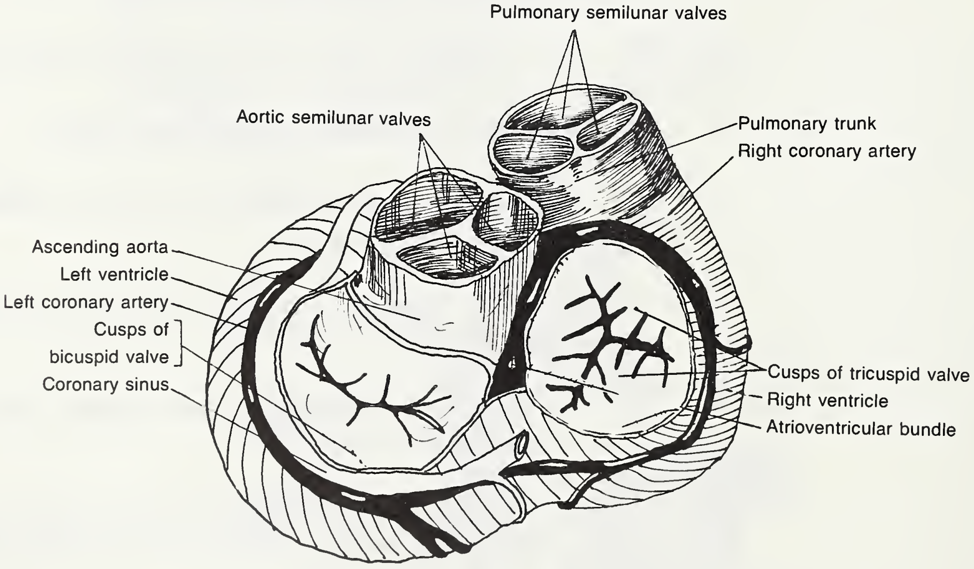


Figure 2: Valves of the Heart

The tricuspid valve is so called because it consists of three flaps or cusps, while the bicuspid valve consists of two flaps or cusps. The cusps or flaps are continuous with each other at their bases. They, therefore, form a ring-shaped membrane which surrounds the passage between the atrium and ventricle. The pointed ends of the cusps project into the ventricle and are attached to small muscular pillars or **papillary muscles** on the walls of the ventricle by cords **(chordae tendineae)**.

Heart beat or heart sounds, the characteristic "lub, dub", are caused by the closing of heart valves; the first part of the sound is caused by the closure of the atrioventricular valves and the second by the **semilunar valves**.

Semilunar valves

Both arteries leaving the heart have valves that prevent blood from flowing back into the heart. These include the semilunar valves, so named because they consist of halfmoon-shaped cusps or flaps. The pulmonary semilunar valve is located in the opening where the **pulmonary artery** leaves the right ventricle. The aortic semilunar valve is situated at the opening between the left ventricle and the **aorta**. Both valves consist of three semilunar cusps. Each cusp is attached to the artery wall. The free borders of the flaps or cusps curve outward and project into the opening of the particular blood vessel. The function of the semilunar valves is similar to that of the atrioventricular valves in that they permit blood to flow in **one direction** only, that is, from ventricles into arteries. Recall that the two main arteries transporting blood from the heart, the aorta and the pulmonary artery,contain semilunar valves.

How the valves work

The tricuspid valve is closed while the atrium is filling with blood. When the atrium is full, a wave of contraction starts at the top of its walls, the valves open and the contraction squeezes the chamber inward and downward forcing blood through the valve into the ventricle. The process completed, the valve closes. A second wave of contraction now starts, but this time at the bottom of the ventricle. The blood is now forced upward through the semilunar valve which lies at the entrance of the pulmonary artery leading to the lungs. With each beat of the heart this process is repeated over and over. The same sequence of valve activity occurs in the left side of the heart.

Similarly, the semilunar valves are actually small flaps of tissue located in the arteries that leave the ventricles. These valves are structured to ensure a one way flow of blood, preventing backflow into the lower chambers of the heart. Their opening and closing are controlled by pressure since they are not attached to muscles.

Major Blood Vessels of the Heart

All mammals including man possess a four-chambered heart which is more efficient than the two or three chambered heart in other vertebrates. The four-chambered heart is more efficient than the other types because it does not allow oxygenated and deoxygenated blood to mix.

The right atrium receives blood from all parts of the body except the lungs. Three major veins return blood to the right atrium. One such vein is the **superior vena cava** which returns blood from the upper portion of the body. A second major vein is the **inferior vena cava** which returns blood from the lower portion of the body. A third major vein is the **coronary sinus** which returns blood from the vessels supplying the heart.

From the right atrium blood is squeezed into the right ventricle from which the blood is pumped into the **pulmonary trunk**. The pulmonary trunk divides into a right and left pulmonary artery each of which lead to one lung. As indicated previously, blood in the right side of the heart is deoxygenated. This blood, when transported to the lungs, releases its carbon dioxide and collects a supply of oxygen. This blood loaded with oxygen is returned to the heart by way of the **pulmonary veins** which empty into the **left atrium**. The atrium contracts forcing the blood into the **left ventricle**. As the ventricle contracts, the oxygenated blood is pumped into the largest blood vessel in the body, the **ascending aorta**. From the ascending aorta blood is distributed to all body parts except the lungs.

From the illustrations contained in this lesson you will observe that the atria are thin-walled while the ventricles are thick-walled. Atria need only reduced pressure to squeeze blood into the ventricles. The left ventricle has the thickest walls since it must pump blood at high pressure throughout the body - head, trunk and limbs.

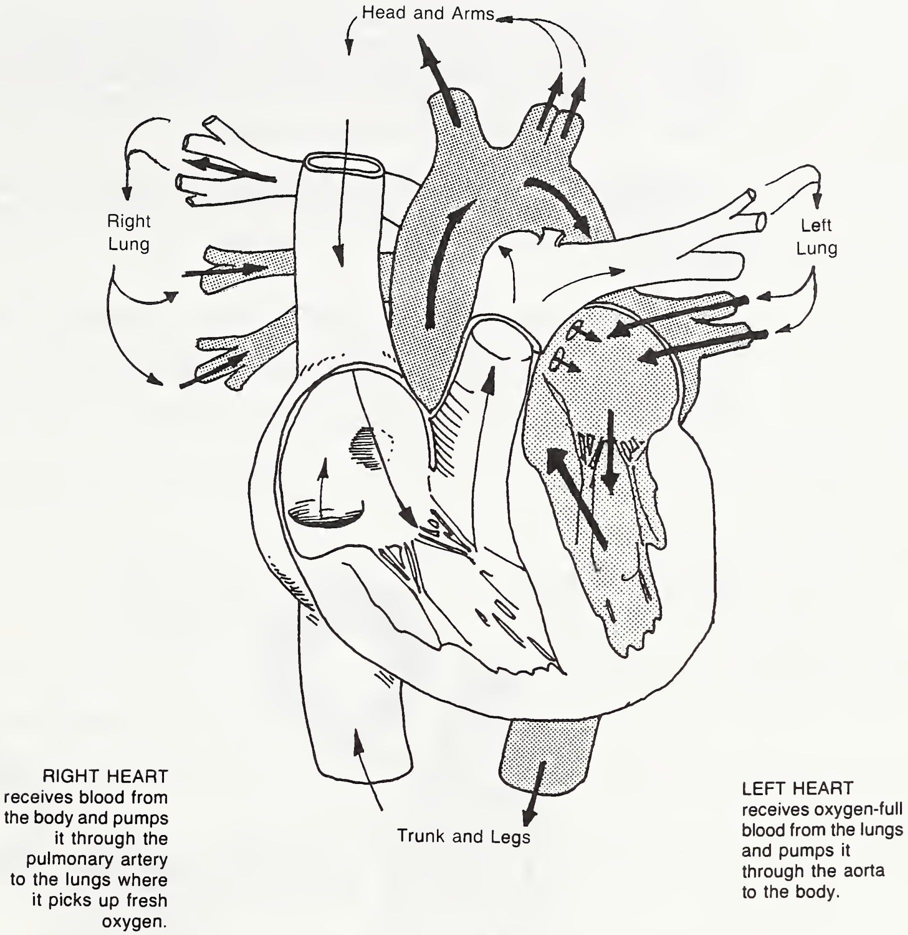

Head and Arms
Right Lung
Left Lung
Trunk and Legs
RIGHT HEART receives blood from the body and pumps it through the pulmonary artery to the lungs where it picks up fresh oxygen.
LEFT HEART receives oxygen-full blood from the lungs and pumps it through the aorta to the body.

Figure 3: The Heart and How It Works

The Blood Vessels

Three kinds of blood vessels are found in the body: arteries, veins and capillaries. Arteries are vessels which transport blood away from the heart and with the exception of the pulmonary artery and its branches, arteries carry oxygen-rich blood. Small arteries are called **arterioles**.

The walls of arteries are thick and are composed of **three´tissue layers**. These include

(a) **Tunica externa** or outer layer
(b) **Tunica media** or middle layer
(c) **Tunica intima** or inner layer

The outermost layer is composed of very tough connective tissue. If an artery is cut this layer prevents it from collapsing (whereas veins collapse when cut). The middle layer is composed of elastic tissue. This layer permits the vessel to constrict and dilate. The inner lining of arteries consists of a tissue called **endometrium**.

Veins transport deoxygenated blood from the capillaries to the heart. You will observe that veins contain the same three layers as the arteries but here the layers are somewhat thinner and contain less elastic fibre. As indicated, when cut, the walls of veins collapse while the walls of arteries remain open. Elsewhere in this lesson you will study closely the presence and function of semilunar valves in veins.

Capillaries are microscopic. Their walls consist of a single layer of flat endothelial cells. It is the capillaries that transport materials to and from each and every body cell. The blood in the capillaries and body cells are able to exchange materials across the thin walls of the capillaries.

Very briefly, arteries distribute oxygen-rich blood to the arterioles. From here the blood enters the capillaries. Capillaries deliver blood to individual cells and veins. The venules and veins return it to the heart from where it is pumped to the lungs for oxygenation. **Please study carefully Figure 10-2** in your text. It shows the action of blood cells and the diffusion of materials between a capillary and the surrounding tissues.

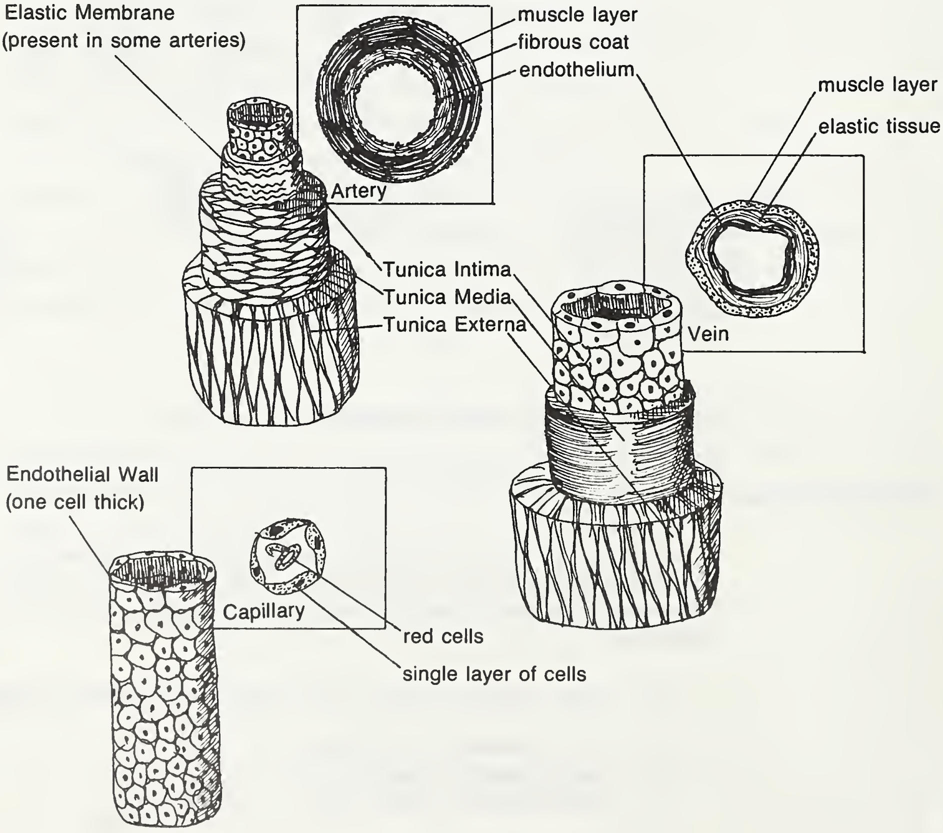


Figure 4: Structure of Blood Vessels

Exercise 2

Answer or complete the following questions.

15. What is the basic function of heart valves?

16. Specify the location of the following:

(a) tricuspid valve:

(b) bicuspid valve:

(c) semilunar valves:

17. What causes heartbeat sounds?

18. List the two main arteries transporting blood from the heart:

(a)

(b)

19. List the two groups (categories) of animals that possess four-chambered hearts.

(a)

(b)

20. Which major vein in the body returns blood from the vessels supplying the heart?

21. Which two arteries transport blood to the lungs?

(a) ______________________________

(b) ______________________________

22. Why does the left ventricle possess such thick walls?

____

____

23. List three kinds of blood vessels found in the human body.

(a) ______________________________

(b) ______________________________

(c) ______________________________

24. List three tissue layers found in an artery of the human body.

(a) ______________________________

(b) ______________________________

(c) ______________________________

25. Which tissue layer in the wall of an artery prevents it from collapsing when cut?

____

26. What is the function of the middle layer of an artery?

____

____

27. Which type of blood vessels has walls composed of a single layer of endothelial cells?

____

____

Please check your answers with those given on page 24.

Veins and Their Valves

Blood pressure in veins is very low. This creates a problem because blood in veins such as those in the upper and lower extremities of the body - arms and legs - still has a long distance to travel back to the heart. Furthermore, veins in such locations expand and blood has a tendency to pool in them.

The circulatory system overcomes such difficulties utilizing a system of valves located in the veins themselves. The valves point in the direction in which the blood is flowing. The valves may be forced open to allow blood to flow toward the heart but they close to prevent backflow.

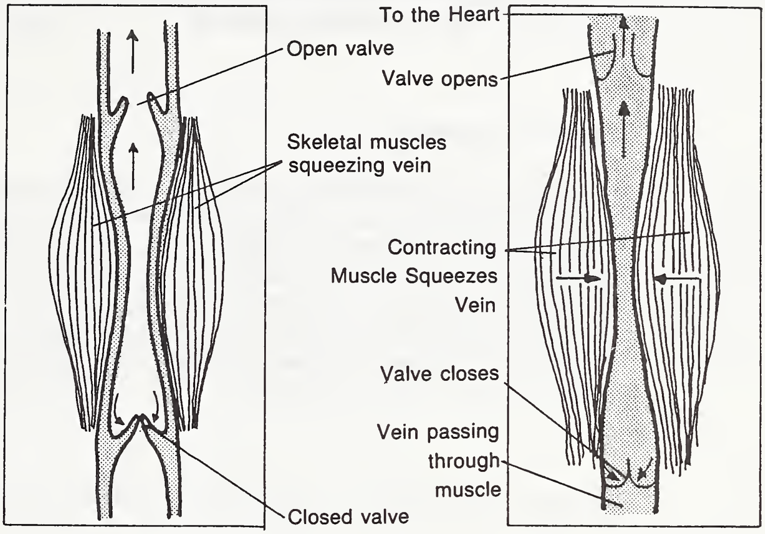

Open valve
Skeletal muscles squeezing vein
Closed valve
To the Heart
Valve opens
Contracting Muscle Squeezes Vein
Valve closes
Vein passing through muscle

Figure 5: Blood Flow in a Vein

Any movement of the body including muscular contraction causes compression of portions of the veins. As muscles surrounding veins contract, they bulge outwards thereby squeezing the veins and pushing the blood forward through the valves. As the valve flaps move back into place the blood cannot flow back into the vein behind the valve. This process is repeated until the blood is squeezed back to the heart. A suction produced by the heart also helps this process. As the ventricles empty, blood returning from the body is pulled in to replace the amount pumped out.

Although the rate of flow is slower in veins than in arteries, veins are more numerous on the whole, hence at any one point in time sufficient blood is being returned to the heart. Varicose veins are the result of failure of the valves in veins. As valves fail to close completely, blood forms bulging pools, hence the veins become swollen due to the amount of blood in them. These swellings, particularly in the legs, cause the veins to appear knotted and blue. A contributing factor to the development of varicose veins is the loss of elasticity in the walls of the veins.

The Heart's Blood Supply

The **right** and **left coronary arteries** supply the heart muscle with blood. The coronary arteries are the first branches of the **aorta**. Other branches are developed from these main arteries to supply the entire heart.

Division of the Circulatory System

The circulatory system of man is made up of several smaller divisions. These include

(a) the **systemic circulatory system**
(b) the **pulmonary circulatory system**
(c) the **portal circulatory system**

Systemic Circulation

Blood vessels in the systemic circulatory system distribute oxygen and nutrients to the individual cells and collect metabolic waste products from the entire body. The aorta is the primary vessel in the systemic system and all other vessels arise as branches of the aorta. Careful observation will show that the aorta emerges from the upper surface of the left ventricle and passes upward just behind the pulmonary artery. The **ascending aorta** is this portion of the vessel. As the vessel turns to the left it becomes the **aortic arch** and as it passes downward it becomes the **descending aorta**. A network of arteries originating at the aorta supplies the entire body with blood.

Pulmonary Circulation

The pulmonary circulatory system is less extensive than the systemic circulatory system. The system is made up of arteries, arterioles, capillaries, venules and veins forming a network of vessels forcing blood through the lungs to be oxygenated. Once oxygenated, four pulmonary veins, two from each lung return the blood to the left atrium. You will be aware that normally, arteries carry oxygenated blood and veins carry deoxygenated blood, but this situation in the lungs is an exception. Here the pulmonary artery transports deoxygenated blood and the four pulmonary veins transport oxygenated blood.

Pulmonary blood pressure is lower than the systemic blood pressure. Also, capillaries used in pulmonary circulation are found to be much more elastic than those used in the systemic circulation. This structural difference is of some value in that these capillaries are able to expand providing more area for gaseous exchange at the alveoli of the lungs.

Hepatic or Portal Circulation

The hepatic portal system arises as a branch of systemic circulation. Normally veins supplying the abdominal region will empty blood directly into the inferior vena cava. Veins supplying the spleen, stomach, pancreas and intestines, however, transport blood to the liver via the hepatic portal vein. This pattern of circulation referred to as hepatic or portal circulation transports the products of digestion such as glucose, amino acids and fats directly to the liver. There is some mixing of arterial and venous blood in the liver. The hepatic vein eventually empties its contents in the inferior vena cava. The liver is one organ with a high rate of metabolic activity. The **hepatic artery** supplies the liver with oxygen required to sustain these activities..

Heart Action

When the superior vena cava, the inferior vena cava and the pulmonary veins receive blood from all parts of the body the blood is passed to the atria. The atria relax and become filled with blood. As the atria contract, the ventricles relax and receive the blood from the atria. When the ventricles contract and force the blood out of the heart, the atria relax and are filled again.

Cardiac Cycle

Cardiac cycle refers to the actions taking place during a single heartbeat. The cardiac cycle consists of a **contraction (systole)** and **relaxation (diastole)** of both atria. This is followed by contraction and relaxation of both ventricles. Blood enters the atria and ventricles during diastole and is pumped out during systole. You can see that the heart does not contract as a unit. Instead the two atria contract simultaneously and as they relax the two ventricles contract. Each cardiac cycle causes blood to flow from the right atrium through the right ventricle and into the pulmonary trunk leading to the lungs and from the left atrium to the left ventricle and to the aorta.

The Conduction System and Nervous Control of the Heart

Nerves entering the heart are from the autonomic nervous system. However, the autonomic neurons or nerves **only increase or decrease** the time it takes to complete a cardiac cycle. In other words, those nerves do not initiate the contraction. You will learn that the heart chambers can continue contracting and relaxing without any direct stimulus from the nerves. In fact, nodal tissue (a highly specialized kind of muscle tissue) functions like nerve tissue in that it can conduct nerve impulses.

Heart muscle therefore has a built-in conduction system. This system consists of specialized heart muscle tissue that generates and distributes electrical impulses which stimulate cardiac muscle tissue to contract.

Four specialized structures make up the conducting system which spreads the cardiac impulse throughout the heart. These are:

(a) the **sino-atrial (sinu-atrial) node or SA node.** The SA node, also called **pacemaker** is located in the wall of the right atrium.

(b) the **atrioventricular node** located in the septum between the right and left atrium. This is also called the AV node.

(c) **Atrioventricular bundle of His**. The bundle of His consists of some elongated masses of nodal tissue extending down through the septum between the ventricles. These masses of nodal tissue extend to the apex or point of the heart.

(d) **Purkinje fibres**. The Purkinje fibres are masses of nodal tissue which break up and extend through the walls of the ventricles.

It is the SA node or **pacemaker** that actually starts each cardiac cycle and therefore sets the basic pace for the heart rate. This is why it is called pacemaker.

As soon as the pacemaker sends out impulses, these impulses cause a wave of contraction to pass over both atria. This results in **atrial systole**. Atrial systole is followed by **atrial diastole**. During diastole blood enters the atria from the superior vena cava and pulmonary veins. The same impulse that caused atrial systole spreads to the AV node located between the right and left atrium. The AV node is then stimulated. It relays an impulse that travels over the bundle of His and Purkinje fibres. These impulses stimulate the walls of the ventricle to contract (systole).

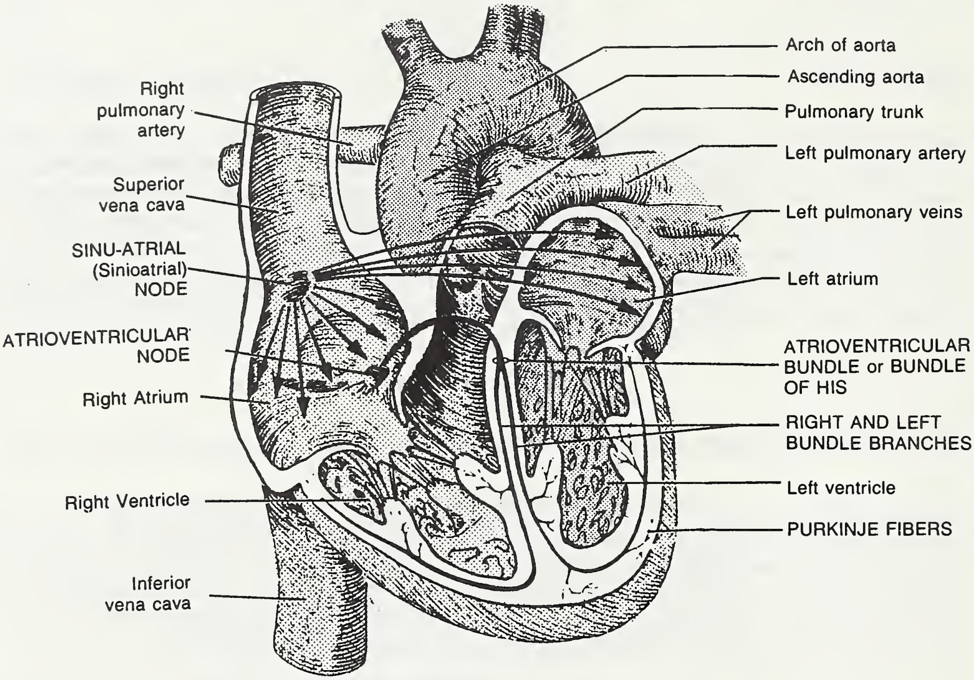


Figure 6: Nerve Conducting Pathways of the Heart

Exercise 3

28. Blood returning to the heart from the limbs is not under high direct pressure. How are these veins adapted for work under such conditions?

29. What are the actual causes of varicose veins?

30. Name the main arteries supplying the heart muscle with blood.

31. List the three main divisions of the circulatory system.

(a)

(b)

(c)

32. From what chamber of the heart does the aorta begin?

33. Veins supplying the spleen, stomach, intestines and pancreas with blood do not return blood directly to the inferior vena cava. The blood is transported to the liver instead. What blood vessel delivers the blood to the liver?

34. Blood from the areas mentioned in the foregoing question eventually reaches the inferior vena cava via the

35. What is the cardiac cycle?

36. The cardiac cycle consists of two stages. List the stages.

(a)

(b)

37. From which branch of the nervous system do nerves entering the heart arise?

38. What is the similarity between nodal tissue of the heart and actual nerve fibres?

39. List the four specialized structures that make up the conducting system which spreads the cardiac impulse.

(a)

(b)

(c)

(d)

Please check your answers with those given on page 25.

Heartbeat Sounds

We should say something here about the way the heart beats. Each beat is actually composed of two parts. The first part is contraction and is called systole. The second part is relaxation and is called diastole.

By using a stethoscope the sounds made by the heart can be amplified and therefore heard. Systole, the first thump of each heartbeat, represents the sound created by the closure of the atrioventricular valves soon after ventricular systole begins. This sound described as a ''lub'' sound is a somewhat long booming sound. The second sound which is heard as a ''dub'' sound is a short, and sharp one. The ''dub'' is the sound created by the closure of the semilunar valves near to the end of the ventricular systole.

The sounds are rhythmically repeated in the characteristic ''lub-dub, lub-dub'' pattern. A cardiac cycle or complete heartbeat consists of the systole and diastole of both atria plus the systole and diastole of both ventricles.

Cardiac Output (The Volume of Blood)

The amount of blood ejected from the **left ventricle** into the aorta per minute is called the **cardiac output** or **minute volume**. Two factors are involved in determining cardiac output. The first is the amount of blood pumped by the left ventricle during each heartbeat. The other factor is the number of beats per minute. Cardiac output in an adult at rest would be about 5 litres per minute. Here is how it is calculated. The amount of blood ejected by a ventricle during each systole is called the **stroke volume**. In an adult at rest the stroke volume is about 70 ml and the heart rate is about 72 beats per minute. Average cardiac output = stroke volume × number of beats per minute.

= 70 ml × 72 beats per minute

= 5 040 ml per minute

approximately 5 litres per minute

During exercise or vigorous activity, cardiac output may rise as high as 25 litres per minute. Well trained athletes may have cardiac output as high as 40 litres per minute.

Cardiac output is controlled, in part, by nerves of the autonomic nervous system. Nerve impulses carried by **sympathetic nerves** to the heart **increase** cardiac output. This is done by increasing both the rate of the heartbeat and the strength of each beat. Opposing the action of the sympathetic nerves are the parasympathetic nerves. Nerve impulses carried to the heart by the **parasympathetic nerves** tend to **decrease** cardiac output by slowing the rate of the heart beat.

Chemical receptors in the blood vessels keep the autonomic nervous system (sympathetic nerves and parasympathetic nerves) informed of changes in the oxygen and carbon dioxide content of the blood. Using this information the heart rate is very precisely regulated.

Blood Pressure

Blood pressure refers to the pressure or force exerted against the walls of blood vessels. Normally the pressure being referred to is arterial pressure (in particular pressure in the brachial artery located just above the elbow). Arterial blood pressure is highest as the ventricles contract. This maximum pressure is measured as **systolic blood pressure**. As the ventricles relax the pressure is lowered considerably. This lowered pressure is measured as **diastolic blood pressure**.

Blood pressure is expressed as a fraction, for example 115/75. The first number (115) represents systolic pressure; the second number (75) represents diastolic pressure. Blood pressure is measured with a sphygmomanometer. Blood pressure in any vessel may vary due to a number of factors, which are listed in your assigned reading.

The Pulse

The alternate expansion and elastic recoil of an artery with each systole of the left ventricle is called the **pulse**. The actual cause of the pulse is the intermittent injections of blood from the left ventricle into the aorta. These injections of blood alternately increase and decrease the pressure in the aorta and its branches. It is the elastic nature of the arterial walls that enables the wall to expand when blood is injected in, and recoil as the heart relaxes. A new pulse is started with each ventricular contraction moving forward as a wave of expansion throughout the arteries.

The pulse can be felt over any of the arteries lying close to the skin. It is strongest in the arteries closest to the heart. As the pulse travels over the arterial system it becomes weaker and disappears completely in the capillaries. The pulse is most frequently taken over the **radial** artery at the wrist. However, many other arteries may be used including the **temporal**, which is above and toward the outside of the eye; the **common carotid** artery, which is on the side of the neck; the **femoral** artery, which is near the pelvic bone and the **dorsalis pedis artery** over the instep of the foot.

The pulse read in an artery does not coincide exactly with the contraction of the ventricle. It does take some time for the pulse wave to travel from the aorta to the arteries. As a diagnostic tool, the pulse provides valuable information regarding heart action, blood vessels and circulation.

DISORDERS OF THE CIRCULATORY SYSTEM

Heart Attack

The importance of coronary blood vessels can be appreciated based on the fact that heart muscle must have a continuous supply of oxygen in order to continue beating. Interference with the coronary blood circulation may have serious effects on the organism or may even be fatal. This interference may be in the form of a blood clot or other object that cuts off the blood supply and hence, food and oxygen to the heart muscle. The area of the heart served by the blocked vessels may be small, in which case the heart attack would be mild. If, however, a large area of the heart muscle is involved, death results quickly.

Although heart attacks happen suddenly, this is often the result of a gradual process of **atherosclerosis**. Atherosclerosis is a form of **arteriosclerosis** which includes many diseases of the arterial walls. But atherosclerosis is a disorder in which the tunica intima of the arteries becomes thickened with fatty materials. The thickening narrows the arteries which easily become clogged, depriving portions of the heart of its blood supply. Heart attacks usually cause a severely painful feeling of pressure in the chest. This pressure is often followed by general weakness, sweating, shortness of breath, nausea, vomiting and sometimes loss of consciousness.

Stroke

A stroke is caused by damage to a part of the brain. A stroke can be brought on by bleeding in the brain caused by the rupture of a blood vessel (artery) or by the formation of a blood clot which blocks an artery in the brain. Nerve cells cannot function without oxygen for more than a minute or two, hence, deprivation of oxygen for any period of time will likely cause damage to such cells. The part of the body controlled by the nerves that are affected, cannot function either. A stroke may result in the inability to speak, or walk or in memory loss. The result of a stroke may be slight or severe, temporary or permanent.

Other forms of disorder affecting the heart and circulatory system include **hypertension** (high blood pressure), **aneurysm** (a bloodfilled sac caused by an outpouching of the wall of a vein or artery) and **varicose veins**.

Exercise 4

40. Define the pulse.

41. What is the actual cause of the pulse?

42. List 3 arteries in the body from which the pulse may be taken.

(a) ____________________

(b) ____________________

(c) ____________________

True or False. Circle your choice.

T F 43. A heart attack may be fatal if a large area of heart muscle is deprived of oxygen.

T F 44. Atherosclerosis is a disorder in which the tunica intima of the arteries become thickened with fatty materials.

T F 45. General weakness, shortness of breath, nausea, profuse sweating and sometimes loss of consciousness are characteristic of heart attacks.

T F 46. A stroke is caused by damage to a part of the brain.

T F 47. A ruptured blood vessel causing bleeding in the brain or the blockage of an artery in the brain due to a blood clot or some other object may bring on a stroke.

T F 48. The result of a stroke may be slight or severe, temporary or permanent.

T F 49. The term hypertension means high blood pressure.

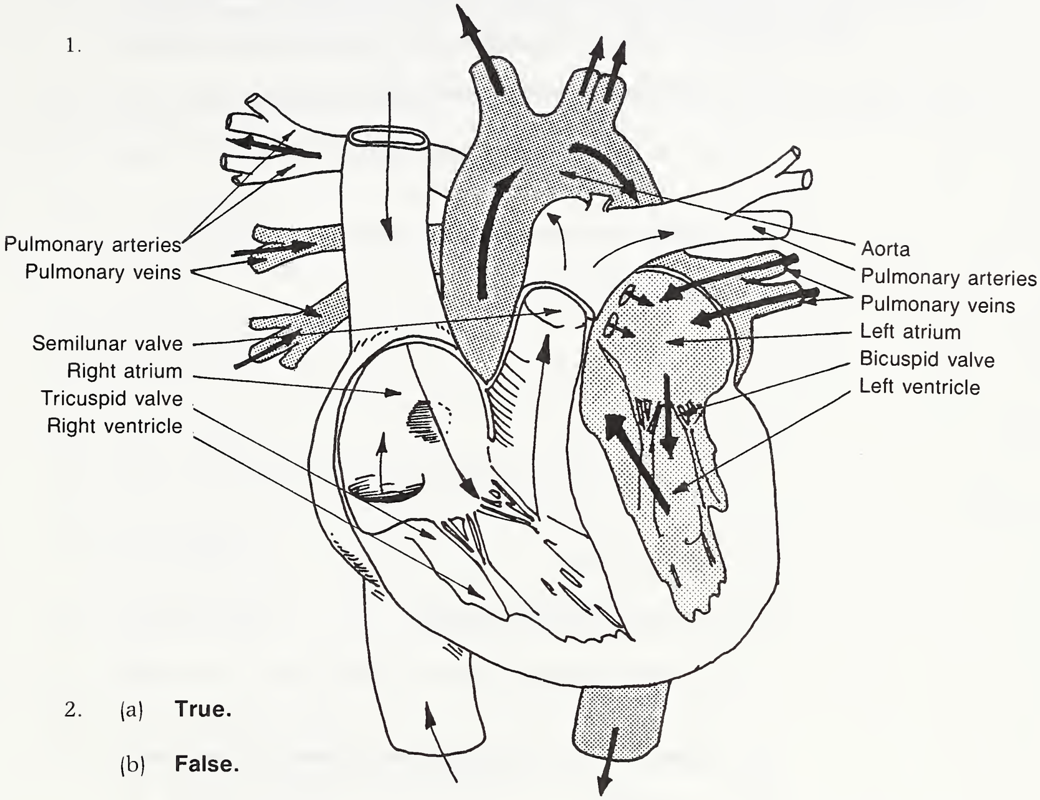
T F 50. An aneurysm is a bloodfilled sac caused by an outpouching of the wall of a vein or artery.

Please check your answers with those given on page 25.

ANSWERS TO SELF-CORRECTING EXERCISES

Exercise 1

1.



2. (a) **True.**

   (b) **False.**

   (c) **True.**

   (d) **False.**

   (e) **True.**

   (f) **True.**

   (g) **False.**

   (h) **True.**

   (i) **False.**

   (j) **True.**

   (k) **False.**

   (l) **False.**

   (m) **False.**

   (n) **True.**

Exercise 2

15. **to prevent backflow of blood into heart chambers**

16. (a) **between the right atrium and the right ventricle**

    (b) **between the left atrium and left ventricle**

    (c) **in the pulmonary artery and in the aorta**

17. **closing of the valves in the heart and arteries**

18. (a) **pulmonary artery**

    (b) **aorta**

19. (a) **mammals**

    (b) **birds**

20. **coronary sinus**

21. (a) **right pulmonary artery**

    (b) **left pulmonary artery**

22. **it pumps blood at high pressure throughout the body**

23. (a) **arteries**

    (b) **veins**

    (c) **capillaries**

24. **Tunica externa**
    Tunica media
    Tunica intima

25. **The external layer**

26. **This layer permits the vessel to constrict and dilate.**

27. **capillaries**

Exercise 3

28. They are supplied with a series of valves that prevents backflow as the blood is forced forward due to muscle contraction. Also, as blood is pumped out of the heart, a suction is created which helps the veinous blood move in.

29. Failure of the valves in the veins; weakening of the walls of blood vessels - veins.

30. right and left coronary arteries

31. (a) systemic
    (b) pulmonary
    (c) portal

32. the left ventricle

33. the portal vein

34. hepatic vein

35. actions taking place during a single heartbeat

36. (a) systole
    (b) diastole

37. the autonomic

38. They both conduct impulses

39. (a) sino-atrial node
    (b) atrioventricular node
    (c) atrioventricular bundle of His
    (d) Purkinje fibres

Exercise 4

40. Alternate expansion and elastic recoil of an artery with each systole of the left ventricle.

41. The intermittent injections of blood from the left ventricle into the aorta.

42. (a) radial artery
    (b) temporal artery
    (c) common carotid artery — any three
    (d) femoral artery
    (e) dorsalis pedis

43. True
44. True
45. True
46. True
47. True
48. True
49. True
50. True

EXERCISES TO BE SENT IN FOR CORRECTION

______ 1. Which of the following is incorrect? The mammalian heart

(a) has four chambers.
(b) lies in the middle section of the thorax between the lungs.
(c) has its apex resting on the diaphragm and pointed to the left.
(d) is positioned to the extreme left of the body's midline.

______ 2. The heart is surrounded by a special membraneous sac, a loose fitting structure called

(a) the pericardium.
(b) the pleural membrane.
(c) the thorax.
(d) the endometrium.

______ 3. Arterial blood is supplied to the heart muscle by

(a) the coronary arteries.
(b) the pulmonary vein.
(c) the femoral artery.
(d) the carotid arteries.

______ 4. Which of the following heart chambers in mammals displays thicker walls than the remaining chambers?

(a) the left atrium
(b) the left ventricle
(c) the right atrium
(d) the right ventricle

______ 5. Two types of valves found in the heart of man are

(a) atrioventricular valves.
(b) semilunar valves.
(c) neither of the above.
(d) both (a) and (b).

______ 6. Heart valves consisting of halfmoon shaped cusps

(a) are called semilunar valves.
(b) are located in the pulmonary artery and great aorta.
(c) prevent blood from flowing back into the ventricles.
(d) (a), (b) and (c) are correct.

______ 7. The heart is endowed with a special system for generating impulses to cause rhythmical contraction of the heart muscle. These impulses are initiated in

(a) the right atrium.
(b) the aorta.
(c) the left ventricle.
(d) the right ventricle.

______ 8. During which part of the cardiac cycle does blood enter the atria from the vena cava and pulmonary veins?

(a) during atrial systole
(b) during atrial diastole
(c) neither of the above
(d) both of the above

______ 9. The circulatory system represents:

(a) the heart and the blood vessels.
(b) the circulating blood.
(c) all circulating fluids.
(d) the flow of materials through the digestive system.

______ 10. An athlete undergoing vigorous exercise is likely to have

(a) increased cardiac output.
(b) increased peristaltic activity.
(c) reduced heart rate.
(d) little transmission of impulses in the sympathetic nerves.

______ 11. Deoxygenated blood travels from heart to lungs via

(a) the pulmonary artery.
(b) jugular vein.
(c) superior vena cava.
(d) the pulmonary vein.

______ 12. The terminal branches of arteries are called

(a) venules.
(b) the portal system.
(c) capillaries.
(d) sinuses.

______ 13. Present in a type of blood vessel is a layer of elastic material enabling such vessels to constrict and dilate freely. The particular vessels are:

(a) veins.
(b) capillaries.
(c) arteries.
(d) none of the above.

______ 14. Which of the following heart chambers on contraction ejects blood into the pulmonary artery?

(a) the right atrium.
(b) the right ventricle.
(c) the left atrium.
(d) the left ventricle.

______ 15. After being oxygenated in the lungs, to which of the heart chambers is the blood returned via the pulmonary veins?

(a) left atrium
(b) left ventricle
(c) right atrium
(d) right ventricle

______ 16. Which blood vessel carries blood to the liver after servicing the spleen, stomach, pancreas and intestine?

(a) the aorta
(b) the hepatic portal vein
(c) the hepatic artery
(d) inferior vena cava

______ 17. The term blood pressure normally refers to

(a) pressure of blood exerted against the walls of the arteries.
(b) cardiac output.
(c) amount of blood found in the circulatory system.
(d) flow of blood through veins.

______ 18. What type of blood pressure occurs during the contraction of the left ventricle?

(a) systolic
(b) diastolic
(c) both the above
(d) none of the above

______ 19. The pulse may be defined as the

(a) alternate expansion and recoil of an artery.
(b) contraction of a muscle fibre.
(c) the contraction and relaxation of the heart itself.
(d) none of the above.

______ 20. Which of the following possess a closed circulatory system?

(a) the amoeba
(b) the grasshopper
(c) mammals and birds
(d) none of the above

______ 22. Heart rate may be

(a) primarily automatic.
(b) influenced by nervous and chemical control.
(c) both (a) and (b).
(d) none of the above.

Complete the following statements.

23. The heart is surrounded by a special membraneous sac called the ______________ .

24. The interior of the heart is divided into four chambers. The two upper chambers are the ____________ and the two lower ones the ______________ .

25. Blood is pumped to the lungs by contraction of the __________ __________.

26. The two types of valves found in the heart and blood vessels are ______________ and ______________.

27. The arteries supplying the heart muscle with food and oxygen are the ______________ arteries.

28. The three basic kinds of blood vessels found in the body are ______________ , ______________ and ______________ .

29. Three divisions of the circulatory system are

(a) ____

(b) ____

(c) ____

30. All major systemic arteries of the circulatory system arise as branches of the ________________.

31. Usually, the term blood pressure is used to indicate pressure existing in the ________________.

32. Arterial blood pressure is highest at the peak of ventricular contraction also called __________________ .

33. Blood pressure observed during relaxation of the ventricles is called ________________ pressure.

34. Blood pressure readings are expressed as fractions. The first number indicates ________________ pressure, while the second number refers to ________________ pressure.

35. The alternate expansion and recoil of an artery is known as the ________________ .

36. In animals with an open circulatory system blood flows in the aorta for a short distance and then enters body spaces called ________________ .

37. What structure would you consider to be the centre of the circulatory system in mammals and birds?

____

38. The kind of muscle found in the heart is __________________ muscle.

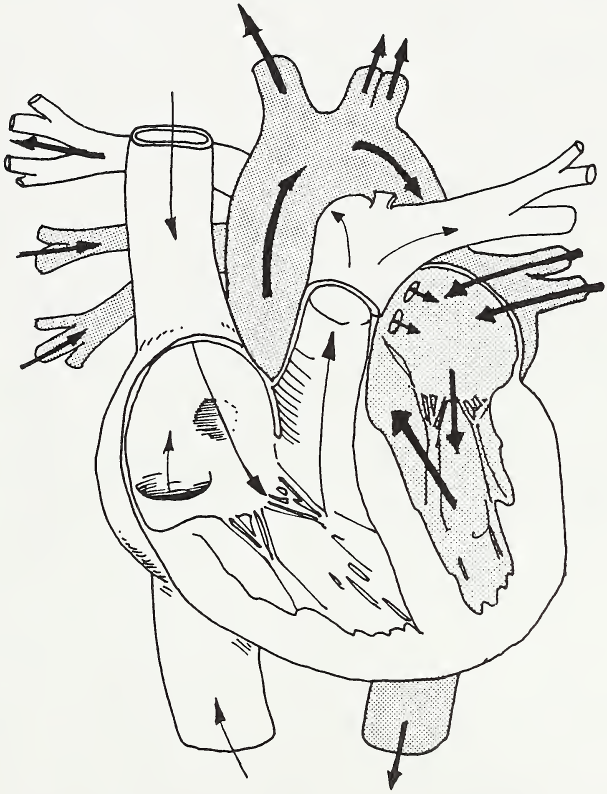
39. How is the heart held in place within the thoracic cavity?

____

40. Heart sounds are produced by the closure of the __________________________ and ____________________ valves.

41. Label the drawing to show:

(a)	Right and left atrium	(e)	Inferior vena cava
(b)	Right and left ventricle	(f)	Pulmonary artery
(c)	Aorta	(g)	Pulmonary vein
(d)	Superior vena cava	(h)	Indicate where the right and left lungs would be located



Please submit pages 26-31 for correction.

END OF LESSON 9

LESSON RECORD FORM

3230 Biology 30

Revised 03/89

FOR STUDENT USE ONLY

Date Lesson Submitted ____________________

Time Spent on Lesson ____________________

(If label is missing or incorrect)

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1. BEFORE MAILING YOUR LESSONS, PLEASE SEE THAT:

(1) All pages are numbered and in order, and no paper clips or staples are used.
(2) All exercises are completed. If not, explain why.
(3) Your work has been re-read to ensure accuracy in spelling and lesson details.
(4) The Lesson Record Form is filled out and the correct lesson label is attached.
(5) This mailing sheet is placed on the lesson.

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Do **not** enclose letters with lessons.

Send all letters in a separate envelope.

3. POSTAGE RATES

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Take your lesson to the Post Office and have it weighed. Attach sufficient postage and a **green first-class sticker to the front of the envelope, and seal the envelope. Correspondence lessons will travel faster if first-class postage is used.**

Try to mail each lesson as soon as it has been completed.

When you register for correspondence courses, you are expected to send lessons for correction regularly. Avoid sending more than two or three lessons in one subject at the same time.